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USAAEFA PROJECT NO. 77-31

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**PRELIMINARY AIRWORTHINESS EVALUATION
CH-47C WITH FIBERGLASS ROTOR BLADES
(with T55-L-712 Engines)**

FINAL REPORT

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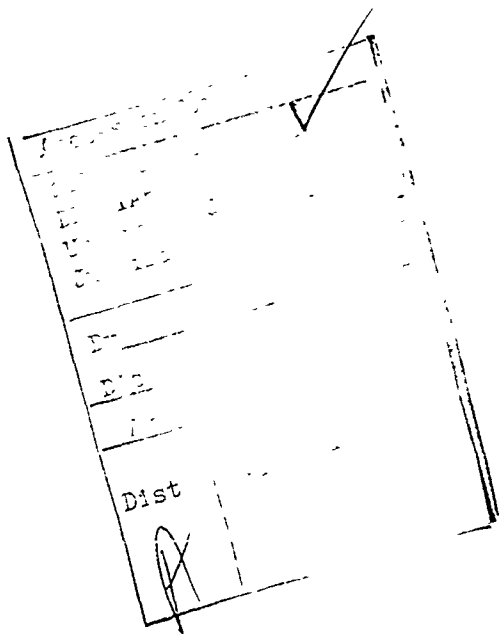
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20 ABSTRACT (Continue on reverse side if necessary and identify by block number) A Preliminary Army Evaluation of a CH-47C helicopter equipped with Fiberglass rotor blades was flown from 31 October through 7 November 1978. A total of 22 hours, 12 of which were productive, was required. Tests were conducted at the Boeing Vertol test facility at Wilmington, Delaware. Fiberglass rotor blades at a rotor speed of 225 rpm have improved hover performance in terms of decreased power required when compared to metal blades at the operating rotor speeds of 235 and 245 rpm. There is an improvement in level flight performance in terms of a			

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20. ABSTRACT

↙ reduction in power required between fiberglass blades at a rotor speed of 225 rpm compared to metal blades at a rotor speed of 245 rpm. Handling qualities, for all conditions tested, were essentially the same as with metal rotor blades and are satisfactory. Five shortcomings were identified, only two of which were related to the fiberglass rotor blades. The fiberglass blade related shortcomings were (1) the high six-per-rotor-revolution (6/rev) (22.5 Hz) vibration levels in the vicinity of the cargo hatch and ramp area at light gross weight and airspeeds of 100 knots calibrated airspeed (KCAS) and above; and (2) high vibration levels (3 and 6/rev) throughout the aircraft at airspeeds of 140 KCAS and above. The other shortcomings are standard CH-47C problems that remain unchanged with fiberglass rotor blades and were associated with excessive cabin noise levels, lack of adequate intercom/radio audio gain when using earplugs and poor power management characteristics. The cruise guide indicator (CGI) provides useful information to the pilot for recognizing and recovering from the effects of aft rotor stall. Engine start sequence and switchology were improved.





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MAY 25 1979

SUBJECT: USAAEFA Project No. 77-31 Preliminary Airworthiness Evaluation
CH-47C With Fiberglass Rotor Blades (With T55-L-712 Engines)

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1. The purpose of this letter is to present the Directorate for Development and Engineering position on the subject report.
2. Specific comments by paragraph are:
 - a. Abstract, 4th and 5th sentences - Test results indicated that CH-47C with the fiberglass rotor blades has increased hover and level flight performance over the CH-47C with the metal blades. However, insufficient testing was conducted to define the extent of the improvement.
 - b. Paragraph 39 - Agree with the general conclusions of this report.
 - c. Paragraphs 40a and 40b - These shortcomings document significant increased 3 and 6/rev vibration levels in the cockpit and cabin areas over the CH-47C with the metal blades. Following the AEFA PAE the contractor found that six of the ten aft pylon mounting bolts were under-torqued and that a through-bolt slip bushing on the forward swiveling actuator was missing. The preceding maintenance deficiencies were corrected and the helicopter was subsequently flown jointly on two flights by the contractor and the US Army Aircraft Development Activity (ADTA) at Fort Rucker, AL. Vibration data recorded during these flights, as well as qualitative pilot and crew chief comments, established that there was a significant improvement in the vibration levels when compared to those obtained during the AEFA PAE. Vibration levels in both the cockpit and cabin areas were reported as being similar or lower than a CH-47C with metal rotor blades. Continued RAM testing by ADTA at Fort Rucker should substantiate that the vibration levels are satisfactory. The induced vibration characteristics caused by the fiberglass rotor blades will be further evaluated on the CH-47D during the scheduled AEFA PAE September 1979.
 - d. Paragraphs 40c and 40e - The shortcomings identified in these paragraphs have been documented in previous AEFA reports and no corrective action is planned.

MAY 25 1979

DRDAV-EQ

SUBJECT: USAAEFA Project No. 77-31 Preliminary Airworthiness Evaluation
CH-47C With Fiberglass Rotor Blades (With T55-L-712 Engines)

e. Paragraph 40d - The lack of adequate intercom/radio gain when using earplugs is a new shortcoming. However, it should be noted that this shortcoming is associated with the use of conformal earplugs by crew members and not the communications system. Corrective action is not planned at this time. However, since the conformed ear plugs are in wide use the available intercom/radio gain levels should be increased.

f. Paragraph 41 - While the vibration levels did not meet the requirements of MIL-8501A there was no contractual requirement for the CH-47C with fiberglass rotor blades to meet the specification. Additionally, correction of the maintenance deficiencies and the preliminary results of subsequent flight testing, as discussed above, indicates that the high vibration levels reported in this report have been reduced.

g. Paragraphs 42 and 43 - Concur with the general and specific recommendations.

3. Since the flight characteristics of the CH-47C with the fiberglass rotor blades are similar to those exhibited by the CH-47C with the metal blades installed, this configuration is considered airworthy from a flying qualities point of view.

FOR THE COMMANDER:



WALTER A. RATCLIFF
Colonel, GS
Director of Development
and Engineering

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INTRODUCTION

BACKGROUND

1. As part of a continuing product improvement and modernization program for the CH-47 medium lift helicopter, the Army is considering incorporation of the fiberglass rotor blade on the CH-47C fleet. The fiberglass rotor blade was designed, fabricated, and tested by the Boeing Vertol Company as an integral part of the CH-47D modernization program.
2. Glass fiber blades provide potential for greatly improved ballistic tolerance and thus enhance combat survivability. Combined with potential infinite life and field repair capabilities, the fiberglass rotor blade offers the possibility of significant reductions in the life cycle cost of the CH-47 fleet.
3. A test request (ref 1, app A) issued by the United States Army Aviation Research and Development Command (AVRADCOM) directed the United States Army Aviation Engineering Flight Activity (USAAEFA) to conduct a Preliminary Airworthiness Evaluation (PAE) of the CH-47C with fiberglass rotor blades.

TEST OBJECTIVES

4. The test objectives were:
 - a. Determine if performance of the CH-47C with fiberglass rotor blade is at least equivalent to the production CH-47C.
 - b. Determine compliance with military specification MIL-H-8501A (ref 2, app A).
 - c. Determine compliance with the system specification for the CH-47C (ref 3, app A).

DESCRIPTION

5. The CH-47C is a twin-engine, turbine-powered, tandem rotor cargo helicopter manufactured by the Vertol Division of the Boeing Company (Boeing Vertol). A detailed description of the CH-47C helicopter is contained in the operator's manual (ref 4, app A). For this evaluation the aircraft center of gravity (cg) limits were expanded. A description of the test helicopter and fiberglass rotor blades is also contained in appendix B. The test helicopter, S/N 74-22287 (Boeing production number B-706), was a standard production CH-47C with the following exceptions:

- a. Calibrated/instrumented T55-L-712 engines.
- b. Fiberglass rotor blades.

- c. Modified cockpit self-tuning vibration absorbers.
- d. Aft pylon fixed, tuned absorbers removed.
- e. Modified aft pitch links on forward head.
- f. Modified forward transmission cover actuator mount lugs.
- g. Modified swiveling actuator lower mount bearing and attachment hardware.
- h. Rotor hub lightning protection provisions.
- i. Modified longitudinal speed trim box (altitude bias supplied to aft head).

TEST SCOPE

6. The PAE was conducted in 12 flights for a total of 22 hours, of which 13 were productive. Testing was conducted in the vicinity of the Greater Wilmington, Delaware Airport (80-foot elevation) from 31 October through 7 November 1978. The contractor installed, calibrated, and maintained the instrumentation and performed all maintenance on the test aircraft. Flying qualities were evaluated against the requirements of MIL-H-8501A. Limited performance testing was conducted to compare the aircraft capabilities with the CH-47C equipped with metal rotor blades. Handling qualities were compared with the results of Army Preliminary Evaluation (APE) III and IV and Airworthiness and Flight Characteristics tests (A&FC) for the CH-47C (refs 5 through 7, app A). The CH-47C with fiberglass rotor blades was tested at the general conditions listed in table 1.

7. The flight restrictions and operating limitations applicable to the PAE are contained in the operator's manual and the airworthiness release (ref 8, app A).

TEST METHODOLOGY

8. The test methods utilized were standard engineering flight test techniques (refs 9 and 10, app A) and are briefly described in appendix D.

9. Qualitative ratings of the handling qualities were based on the Handling Qualities Rating Scale (HQRS) contained in appendix D. Qualitative vibration assessment was in accordance with the Vibration Rating Scale (VRS) contained in appendix D.

10. Data were recorded by hand, on magnetic tape on board the aircraft, and via telemetry to the Boeing Vertol STARLAB located at Philadelphia, PA. A detailed listing of test parameters is contained in appendix C.

Table 1. General Test Conditions.

Type of Test	Average Gross Weight (lb)	Center of Gravity Location (FS)	Density Altitude (ft)	Outside Air Temperature (°C)	Trim Calibrated Airspeed (kt)	Rotor Speed (rpm)
Hover performance	Note ¹	327 to 331 (mid)	Sea level	9	0	220-240
Level flight performance	32,000 to 46,000	330 to 332 (mid)	3000 to 9000	2 to 11	40 to 160	222 to 226
	33,000 to 45,000	343 (aft) 334.5 (aft)	5000	8	75, 124, 125 65	225
Maneuvering stability	31,500	343 (aft)	5000	9	67 & 130	225
Dynamic stability	46,000	335 (aft)	5000	8	60 & 100	225
Controllability hover	47,000	334.5 (aft)	-700	8	0	224
	46,500		5000	6	65 & 100	

¹Tethered hover effective gross weight. 35,000 to 48,000 pounds at 10 and 150 feet aft wheel height

RESULTS AND DISCUSSION

GENERAL

11. Performance and handling qualities of a CH-47C helicopter with fiberglass rotor blades were evaluated at the Boeing Vertol test facility at the Greater Wilmington Airport, Wilmington, Delaware (elevation 80-feet). Fiberglass rotor blades at a rotor speed of 225 rpm have improved hover performance in terms of decreased power required when compared to metal blades at the operating rotor speeds of 235 and 245 rpm. There is an improvement in level flight performance in terms of a reduction in power required between fiberglass blades at a rotor speed of 225 rpm compared to metal blades at a rotor speed of 245 rpm. Handling qualities, for all conditions tested, were essentially the same as with metal rotor blades and are satisfactory. Five shortcomings were identified, only two of which were related to the fiberglass rotor blades. The fiberglass blade related shortcomings were (1) the high six-per-rotor-revolution (6/rev) (22.5 Hz) vibration levels in the vicinity of the cargo hatch and ramp area at light gross weight and airspeeds of 100 knots calibrated airspeed (KCAS) and above; and (2) high vibration levels (3 and 6/rev) throughout the aircraft at airspeeds of 140 KCAS and above. The other shortcomings are standard CH-47C problems that remain unchanged with fiberglass rotor blades and were associated with excessive cabin noise levels, lack of adequate intercom/radio audio gain when using earplugs and poor power management characteristics. The cruise guide indicator (CGI) provides useful information to the pilot for recognizing and recovering from the effects of aft rotor stall. Engine start sequence and switchology were improved.

PERFORMANCE

Hover Performance

12. Hover performance of the CH-47C with fiberglass rotor blades was evaluated using the tethered hover method. The tests were flown at the conditions listed in table 1 using the techniques and data analysis methods described in appendix D. Test results are presented in figures 1 and 2, appendix E for an in ground effect (IGE) hover at an aft wheel height of 10 feet and for an out of ground effect (OGE) hover at an aft wheel height of 150 feet.

13. Figures A and B following present the nondimensional fiberglass rotor blade test results at a 150- and 10-foot hover. Also shown are the metal rotor blade hover results from USAAEFA project 66-29 (ref 5, app A) for referred rotor speeds of 245 and 200 rpm. The data show that the fiberglass rotor blades at 225 rpm, which is the fiberglass blade operating speed at all gross weights, have essentially the same performance as metal rotor blades at a referred rotor speed of 200 rpm (no compressibility, base-line rotor speed). However, the metal rotor blades are required to operate at a rotor speed of 235 rpm for gross weights up to 40,000 pounds and at a rotor speed of 245 rpm for gross weights above 40,000 pounds giving the fiberglass blades an improvement in hover performance at all gross weights. Figure A shows that on a sea-level standard-day, at an OGE hover and a gross weight of 40,300 pounds ($C_T = 60 \times 10^{-4}$), there was an improvement in hover performance in

FIGURE A
 NON-DIMENSIONAL HOVER PERFORMANCE
 CH-47C USA S/N 74-22287
 150 FOOT TETHERED HOVER
 OUT OF GROUND EFFECT

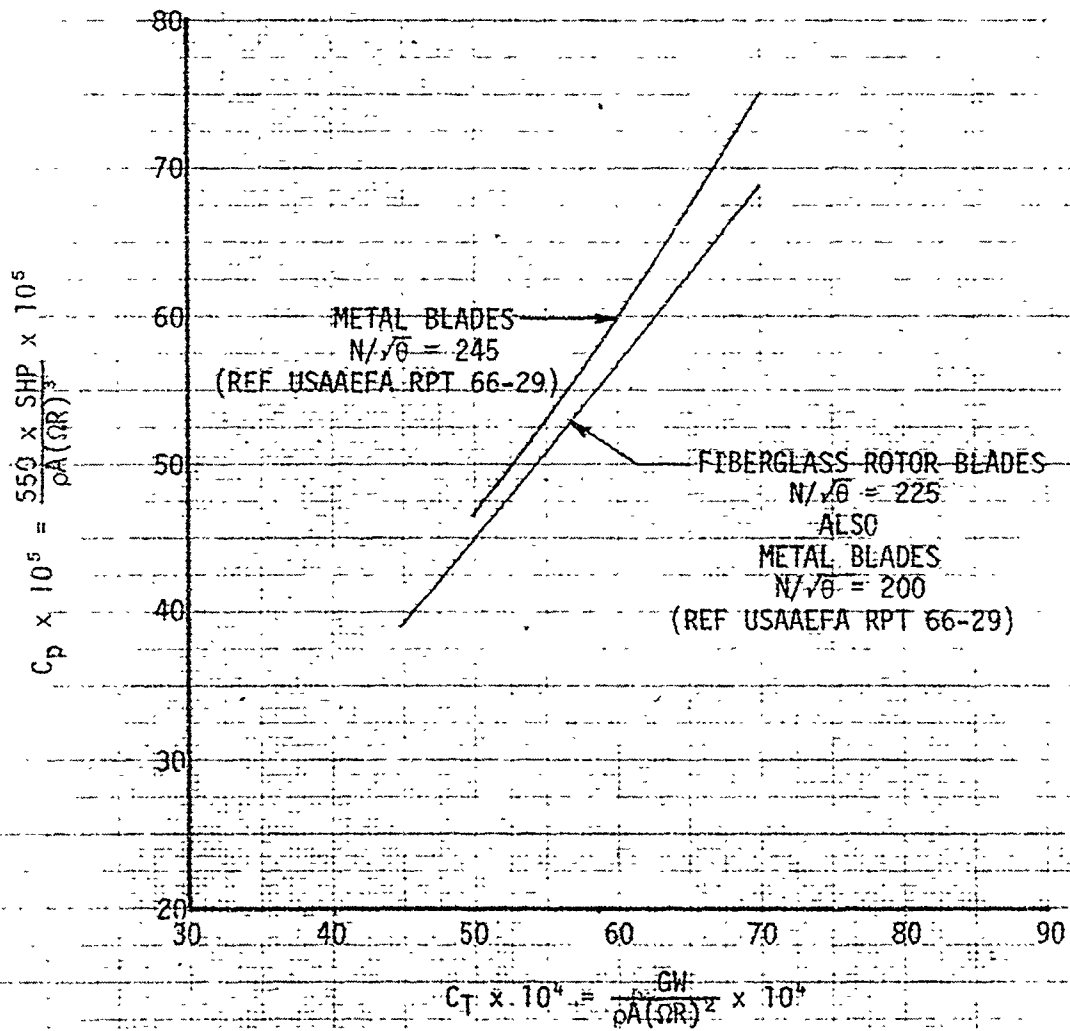
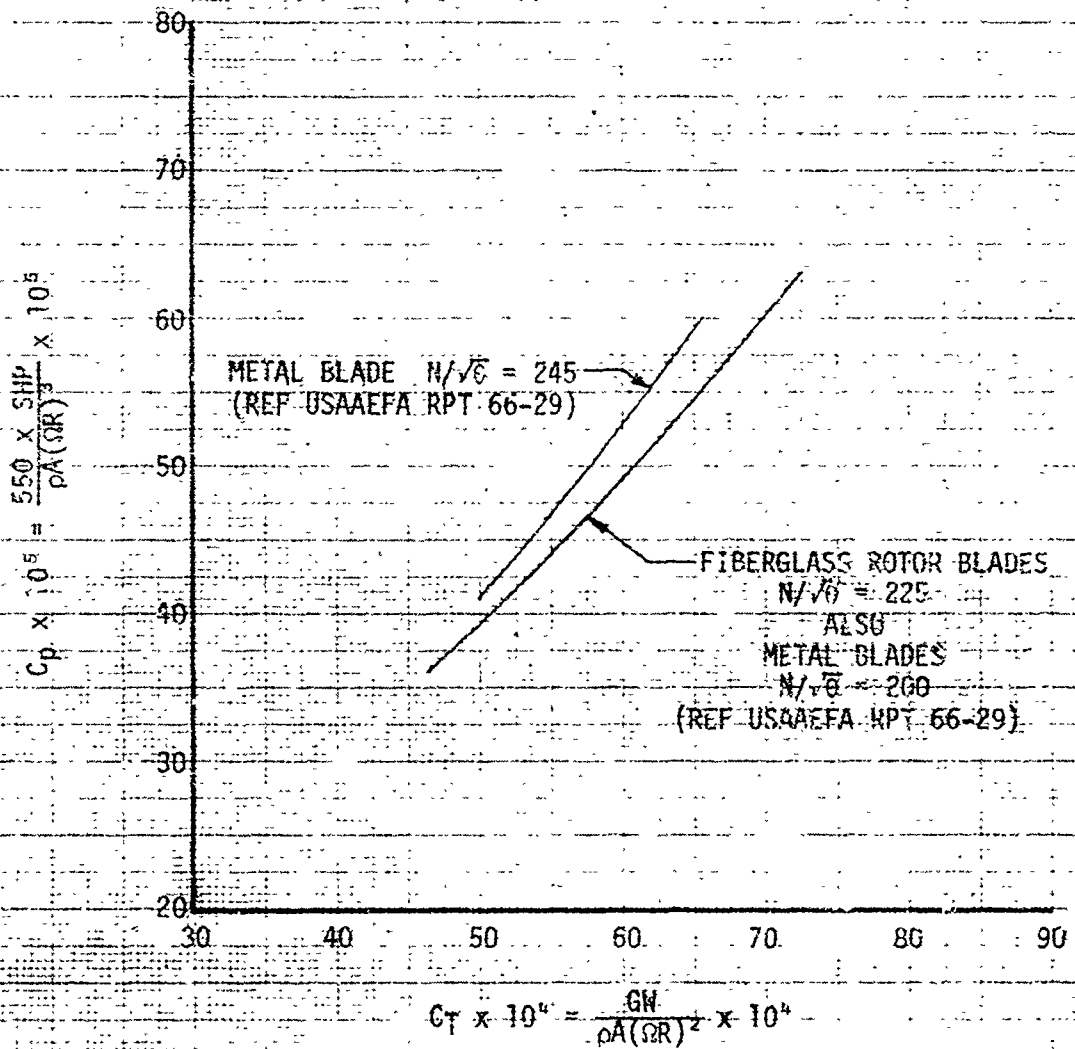


FIGURE B
 NON-DIMENSIONAL HOVER PERFORMANCE
 CH-47C USA S/N 74-22287
 10 FOOT TETHERED HOVER
 IN-GROUND EFFECT



terms of decreased power required of approximately 5 percent for fiberglass rotor blades at 225 rpm when compared to metal rotor blades at 245 rpm. When fiberglass blade performance at 225 rpm is compared to metal blade performance at 235 rpm, there is less improvement. The data also show that the performance improvement is greater at higher gross weights (C_T) than at lower gross weights. Additionally, IGE hover performance data at an aft wheel height of 10 feet, presented in figure B, show the same trends noted in an OGE hover, but with slightly greater performance improvement. Fiberglass rotor blades at a rotor speed of 225 rpm have improved hover performance in terms of decreased power required when compared to metal blades at all operating rotor speeds.

Level Flight Performance

14. Level flight performance of the CH-47C with fiberglass rotor blades was evaluated at the conditions listed in table 1, using the test techniques and data analysis methods described in appendix D. A constant referred rotor speed of 225 rpm was used. Test results are presented in figures 3 through 5, appendix E.

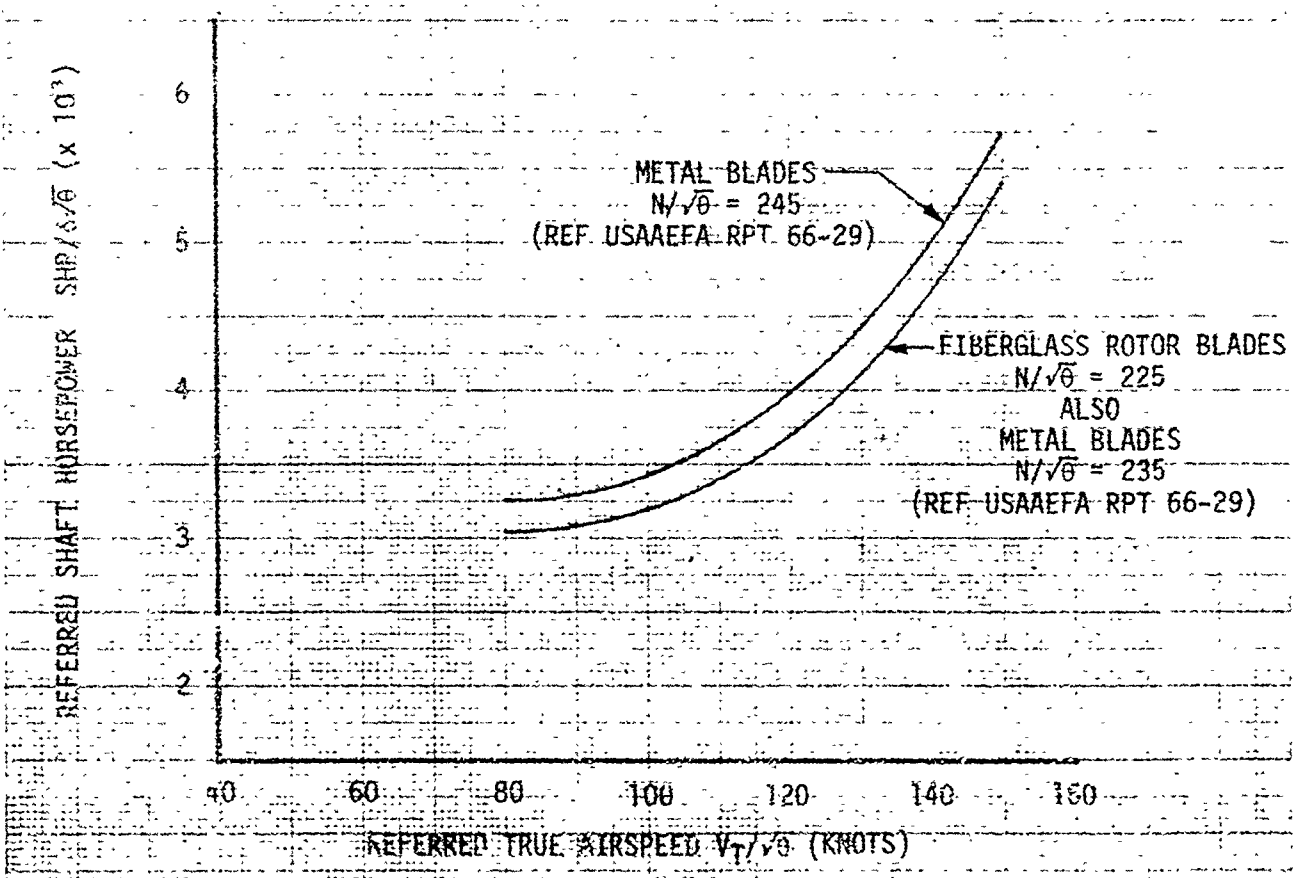
15. Figure C presents the results of level flight performance at a referred gross weight of 40,300 pounds. Also shown are level flight performance results with metal rotor blades from USAAEFA report No. 66-29 (ref 5, app A) for referred rotor speeds of 235 and 245 rpm at the same value of referred gross weight. The fiberglass rotor blade performance at 225 rpm is essentially the same as metal rotor blade performance at 235 rpm. At a referred gross weight of 40,300 pounds on a sea-level standard day the improvement in performance is equivalent to a reduction in power required of approximately 8.5 percent or a 7-knot increase in cruise true airspeed for fiberglass rotor blades at 225 rpm when compared to metal rotor blades at 245 rpm. There is an improvement in level flight performance in terms of a reduction in power required between fiberglass blades at 225 rpm compared to metal blades at a rotor speed of 245 rpm.

HANDLING QUALITIES

Control Positions in Trimmed Forward Flight

16. Trim control positions were evaluated in conjunction with level flight performance tests at the conditions listed in table 1, using the test techniques described in appendix D. All evaluations were conducted with pitch stability augmentation system (PSAS) in the AUTO mode. A representative plot of control positions versus airspeed is included as figure 6, appendix E. The longitudinal control position gradient was not conventional, in that increased aft control position was required to trim at increased airspeed; however, this was not readily apparent to the pilot and therefore was not objectionable. Both lateral and directional control trim changes were minimal (less than 3/4 inch) throughout the airspeed range evaluated. The pitch attitude change with airspeed was linear and varied from 2 degrees nose-up at 52 KCAS to 6 degrees nose-down at 150 KCAS, and provided the pilot with adequate cues to airspeed variations. The trim control position characteristics of the CH-47C were essentially the same as the CH-47C with metal blades and are satisfactory.

FIGURE C
 LEVEL FLIGHT PERFORMANCE
 CH-47C USA S/N 74-22287
 FIBERGLASS ROTOR BLADES



Static Longitudinal Stability

17. Static longitudinal stability characteristics were evaluated at the conditions listed in table 1 using the test techniques described in appendix D. Tests were conducted at two gross weights and two cg locations. The PSAS was in both the OFF and NORMAL mode. Test results are presented as figures 7 through 11, appendix E.

18. The variation of longitudinal control position with airspeed indicated that the aircraft was statically unstable with PSAS OFF (figs. 8 through 11, app E). With PSAS in the NORMAL mode, positive stability was indicated (fig. 7). The variation of lateral and directional control position with airspeed was minimal for all conditions tested. The static longitudinal stability characteristics of the CH-47C with fiberglass rotor blades are essentially the same as with metal rotor blades and are satisfactory with PSAS in the NORMAL mode.

Static Lateral-Directional Stability

19. Static lateral-directional stability characteristics were evaluated at the conditions listed in table 1, using the techniques described in appendix D. Test results are presented as figures 12 and 13, appendix E. The variation of directional control positions with sideslip was essentially linear and indicated positive stability. Directional control position gradients were essentially the same at both airspeeds. Dihedral effect, as indicated by the variation of lateral control displacement with sideslip, was also positive, with increasing right lateral control required for increasing right sideslip. Longitudinal control displacement with sideslip was minimal. Sideforce characteristics, as evidenced by the variation of bank angle with sideslip, were linear and positive. At the lower test airspeed (64 KCAS), minimum pilot cues were not available to determine an out-of-trim condition (ball not centered) for sideslip angles as large as 10 degrees. At an airspeed of 120 KCAS, the sideforce pilot cues to an out-of-trim condition were stronger and readily apparent at sideslip angles greater than 5 degrees. Within the scope of this test, the static lateral-directional characteristics of the CH-47C with fiberglass rotor blades are essentially the same as with metal blades and are satisfactory.

Maneuvering Stability

20. The maneuvering stability characteristics of the CH-47C with fiberglass rotor blades were evaluated at the conditions listed in table 1, using the test techniques and data analysis methods described in appendix D. Test results are presented as figures 14 and 15, appendix E.

21. At a trim airspeed of 136 KCAS with PSAS OFF, the gradient of longitudinal control position versus load factor was positive, in that aft longitudinal control was required with increased normal acceleration. At a trim airspeed of 75 KCAS with PSAS OFF the gradient was neutral to slightly negative, in that some forward longitudinal control was required with increased normal acceleration. At bank angles greater than 45 degrees, considerable pilot effort was required to maintain trim airspeed ± 5 KCAS due to aft rotor "dig-in" tendency. This "dig-in" was accompanied by increased CGI activity and was easily recovered by lowering the thrust

control rod (see para 38). Aft control force was required during maneuvering and except during "dig-in" provided good pilot cues for g control even with the neutral control position gradient. Maneuvering stability characteristics with PSAS OFF are satisfactory for a degraded mode.

22. Qualitative evaluation of maneuvering flight with PSAS NORMAL indicated positive stability at all test conditions. Maneuvering flight characteristics of the CH-47C with fiberglass rotor blades are essentially the same as the production CH-47C with metal blades and are satisfactory.

Dynamic Stability

23. The dynamic stability characteristics of the CH-47C with fiberglass rotor blades were evaluated at the conditions listed in table 1, using the test techniques described in appendix D. The aircraft short-period response in all axes, long-period response, and lateral directional oscillations (Dutch roll) were tested. All dynamic stability tests were evaluated with PSAS in the NORMAL position.

24. The short-period response in the longitudinal axis for both forward and aft pulse inputs was deadbeat at trim airspeeds of 60 and 100 KCAS. The lateral short-period response for left and right pulse inputs was also deadbeat. The directional short-period response was heavily damped, with two to three overshoots. The short-period response of the CH-47C with fiberglass rotor blades was essentially the same as with metal rotor blades and is satisfactory.

25. Long-period response characteristics were evaluated at trim airspeeds of 60 and 100 KCAS. The long-period response at all airspeeds and all cg's and gross weights tested was a well-damped return to trim with three to four overshoots. The long-period response characteristics of the CH-47C with fiberglass rotor blades were essentially the same as with metal rotor blades and are satisfactory.

26. Lateral-directional (Dutch roll) characteristics were evaluated at trim airspeeds of 60 to 100 KCAS using a release from steady-heading sideslip and pedal doublet input. At all conditions tested, lateral-directional response was heavily damped with one or two overshoots and in all cases excited the long-period response, which behaved as described in paragraph 25. The lateral-directional characteristics of the CH-47C with fiberglass rotor blades were essentially the same as with metal rotor blades and are satisfactory.

Controllability

27. Controllability characteristics of the CH-47C with fiberglass rotor blades were measured about all axes during level flight at 66 and 101 KCAS and during stabilized 30-foot hover. Tests were conducted at the conditions listed in table 1, using the techniques described in appendix D. PSAS was in the NORMAL mode. Test results are presented as figures 16 and 17, appendix E, for hover and figures 18 through 21 for level flight.

28. Where applicable, the test results were compared with results from USAAEFA Report No. 66-29 (ref 6, app A). The data showed good agreement between the previously documented metal blade controllability characteristics and the fiberglass blade characteristics. Qualitative pilot comments also substantiate the similarity of the two rotor systems. Within the scope of this test the controllability characteristics of the CH-47C with fiberglass rotor blades are essentially unchanged from the CH-47C with metal rotor blades and are satisfactory.

VIBRATION

29. Throughout the conduct of the PAE, vibrations in the cockpit and cabin area were continuously monitored and evaluated both qualitatively and quantitatively. A list of vibration accelerometers and their locations is presented in appendix C. Figures 22 through 25, appendix E, present a summary of vibration levels at various locations throughout the aircraft as a function of airspeed at 32,000 pounds gross weight.

30. Qualitatively, cockpit vibrations were lower at heavier gross weight than at light gross weight (33,000 pounds or less). There was a general increase in the 6/rev vibration levels (22.5 Hz) when compared with a standard metal rotor bladed CH-47C. In hovering flight vibration levels were moderately high, with a value of 5 to 6 on the VRS (fig. 2, app D), but decreased to a level of 4 once through translational lift. In forward flight, vibration levels were moderate and acceptable to approximately 135 KCAS (VRS 3 to 4). At 140 KCAS the vibration level increased sharply (VRS 6), rapidly increasing to an unacceptable level at 150 KCAS (VRS 7 to 8). On the first three flights at light gross weight, vibration absorber bottoming occurred between 150 and 155 KCAS. Subsequent flights under similar conditions did not produce absorber bottoming in the same airspeed range. Because of the severe vibrations encountered, pilots will generally not fly the aircraft above 140 KCAS, even though at light gross weight (below 33,000 pounds) and 2000 feet density altitude the airspeed limit is 165 KCAS and at normal rated power (84% torque at 225 rpm) the aircraft will fly 145 to 150 KCAS. Vibration levels also increased significantly during partial powered descents (VRS 5 to 6). Vibration levels did not increase appreciably in climb.

31. In the aft cabin area, qualitative vibration levels were higher than for the cockpit. There was also an apparent increase in the 6/rev vibration levels when compared with a standard metal bladed CH-47C; however, with two exceptions, the cabin area vibrations followed the same trends as in the cockpit and were satisfactory to approximately 140 KCAS, at which point vibration levels throughout the aircraft increased rapidly to unacceptable levels with increasing airspeed. The two exceptions to satisfactory vibration levels were the area just forward of the ramp (FS 482) and the area surrounding the cargo hatch (FS 320 and 360). Both areas are crew stations during normal CH-47 missions. Abnormally high vibration levels were observed at airspeeds above 100 KCAS on the main structural overhead rib at FS 440 immediately forward of the combining transmission mounting points. The crew chief, an experienced CH-47 technical inspector, stated that he would not have released the aircraft from maintenance with vibrations of the observed mag-

32. Figures 22 through 25, appendix E, present a summary of the 3/rev (11.25 Hz) and 6/rev (22.5 Hz) vibration levels at light gross weight at various stations throughout the aircraft. The data show fairly high 6/rev levels in the cockpit, but as stated in paragraph 30, qualitative cockpit vibration levels were generally acceptable at airspeeds up to 140 KCAS. However, in the aft cabin area, the 6/rev vibration levels were excessively high along FS 320 and 482, subjecting the crew chief to undesirable vibration levels. Qualitatively, the aircraft was smoother at heavy gross weight (above 40,000 pounds) than at light gross weight. During a flight at approximately 46,000 pounds average gross weight (maximum gross weight) the aircraft vibration levels were satisfactory throughout the airspeed range (122 KCAS, *ie*, V_H) in level flight, climbs, partial power descents, and full autorotational flight. This was an improvement over the standard metal bladed CH-47C. However, most training flights and approximately one-half of all mission flights will be at light gross weight with undesirable vibration levels in the aft cabin area. The high 6/rev (22.5 Hz) vibration levels in the vicinity of the cargo hatch and ramp area at light gross weight and airspeeds of approximately 100 KCAS and above are a shortcoming. The high vibration levels (3 and 6/rev) throughout the aircraft at airspeeds of 140 KCAS and above are a shortcoming. The requirements of paragraph 3.7.1(b) of MIL-H-8501A were not met, in that the 6/rev vibrations (22.5 Hz) are consistently in excess of 0.15g at the aft crew stations. The 6/rev vibrations are not currently addressed in the CH-47C detail specification, the test aircraft fiberglass rotor blade system specification (ref 3, app A), or the new CH-47D detail specification.

CABIN NOISE LEVEL

33. Due to the excessively high cabin noise level of the CH-47C, the pilots wore earplugs as well as helmets during the evaluation. With earplugs installed, the audio gain of the aircraft intercom system was inadequate to satisfactorily hear intercom or radio transmissions. If earplugs were not used, the radio and intercom could be heard, but the pilots suffered short-term hearing loss. The lack of adequate intercom/radio audio gain when using earplugs is a shortcoming. The excessive cabin noise level was previously documented by USAAEFA as a shortcoming (refs 5, 6, and 11, app A) for the CH-47C with metal rotor blades and remains unchanged with fiberglass blades.

SUBSYSTEM TESTS

Engine Start

34. The test aircraft was equipped with T55-L 712 engines with modified engine start switches (photo 6, app B) and engine start check list. Following USAAEFA Project No. 77-29 (ref 12, app A), the start switches were modified to enable the pilot to move the start switch from the START position to the MOTOR position without going through the OFF position. Throughout this test, all engine starts had power turbine inlet temperatures less than 600 degrees and were easily accomplished. Start switchology was logical and satisfactory. Engine start switchology and sequence were improved since previous testing and are now satisfactory.

Cruise Guide Indicator

35. A standard CH-47C CGI system was installed on the test aircraft. The CGI measures strain on the pivoting actuator and the fixed link of the aft rotor flight control system through strain gages bonded to these components. A more complete description of the system and operation is contained in the operator's manual. The CGI dial on the test aircraft was marked so that the green band was reduced by one-third to account for higher aft vertical shaft bending caused by the wider chord blades.

36. During controllability tests at 46,500 pounds and extreme aft cg, aft rotor stall was encountered. Stall was evidenced by an increase in vibration levels (particularly 3/rev), mild aircraft buffet, and nose-up pitch. Simultaneously with the physical cues, the CGI showed an increase in needle activity, and as aft rotor stall progressed, the indicator moved from the green band to the yellow band. Recovery was accomplished by lowering the thrust control rod prior to reaching the prohibited red and yellow striped band. In all cases tested, the CGI gave useful information to the pilot for recognizing and recovering from the effects of aft rotor stall. The system works well and should be used. Paragraph 2-242 of the operator's manual describes the CGI system and mentions a number of ways to reduce high CGI indications; however, the best and most immediate method of reducing high CGI indications - lowering the thrust control rod - is not mentioned. Paragraph 2-242 of the operator's manual should be changed to indicate that lowering the thrust control rod is the primary and most immediate method to reduce high CGI indications. The last sentence of paragraph 2-242 should read:

This can be accomplished by lowering the thrust control rod, a slight reduction of airspeed, the release of back pressure on the cyclic stick, or by reducing the severity of the maneuver.

Power Management

37. Power management of the CH-47C was qualitatively evaluated in conjunction with performance and handling qualities testing, as well as during sling load operations with loads of 10,000 and 12,000 pounds.

38. During powered flight, rotor speed control is achieved by the two engine beep trim switches located on the thrust control rod. Once set in flight, rotor speed remained fairly constant through normal power applications. During large power applications, as in lift-off or sling load pick-up and set-down, small rotor speed variations (± 2 rpm) did occur and required increased pilot attention (HQRS 4) or two-pilot operation to monitor. Torque control is primarily achieved by up or down motion of the thrust control rod, with individual engine torque matching being accomplished by the engine beep trim switches. At light gross weight and low power levels (40 to 60 percent) even small power changes frequently resulted in torque splits of 5 to 10 percent. At high power levels (80%), torque matching was better, with 3 to 5 percent being an average split for a 10 to 15-percent power change. The thrust control magnetic brake failed to maintain a precise control/power setting. The condition was observed at all power settings and flight conditions, and was most apparent when the thrust control rod was raised for increased power. After the desired engine torque setting was reached, the magnetic brake trigger released, and

the applied force relaxed; engine torque decreased 2 to 3 percent. When maximum power was required, as in maximum gross weight sling load operations or maximum power climbs, the pilot either held a continuous UP force on the thrust control rod or overtorqued 2 to 3 percent to achieve the desired power level. The poor power management characteristics were previously documented by USAAEFA (refs 6, 7, and 12, app A) and are unchanged by the fiberglass rotor blade installation. The poor power management characteristics of the CH-47C are a shortcoming.

CONCLUSIONS

GENERAL

39. The following conclusions were reached upon completion of the PAE of the CH-47C with fiberglass rotor blades. There were no deficiencies; however, five shortcomings were identified.

a. Fiberglass rotor blades at a rotor speed of 225 rpm have improved hover performance in terms of decreased power required when compared to metal blades at the operating speeds of 235 and 245 rpm (para 13).

b. There is an improvement in level flight performance in terms of a reduction in power required between fiberglass blades at a rotor speed of 225 rpm compared to metal blades at a rotor speed of 245 rpm (para 15).

c. Handling qualities are essentially the same as with metal rotor blades (para 11).

d. Engine start switchology and sequence were improved since previous testing and are now satisfactory (para 34).

e. The CGI system provides useful information to the pilot for recognizing and recovering from the effects of aft rotor stall (para 35).

SHORTCOMINGS

40. The following shortcomings were identified and are listed in order of decreasing importance.

a. High 6/rev (22.5 Hz) vibration levels in the vicinity of cargo hatch and ramp area at light gross weight and airspeeds of approximately 100 KCAS and above (para 32).

b. High vibration levels (3 and 6/rev) throughout the aircraft at airspeeds of 140 KCAS and above (para 32).

c. Excessive cabin noise level (previously documented for metal blades and unchanged with glass blades) (para 33).

d. Lack of adequate intercom/radio audio gain when using earplugs (not a result of fiberglass rotor blades) (para 33).

e. Poor power management characteristics (previously documented for metal rotor blades and unchanged with glass blades) (para 38).

SPECIFICATION COMPLIANCE

41. Within the scope of this test, the CH-47C with fiberglass rotor blades met the requirements of the system specification. The requirements of paragraph 3.7.1(b) of MIL-H-8501A were not met, in that the vibrations (22.5 Hz) are consistently in excess of 0.15g at the aft crew stations.

RECOMMENDATIONS

GENERAL

42. Correct the shortcomings as soon as practicable.

SPECIFIC

43. The CGI section of the operator's manual should be changed to indicate that lowering the thrust control rod is the primary and most immediate method to reduce high CGI indications. The last sentence of paragraph 2-242 of the operator's manual should read:

This can be accomplished by lowering the thrust control rod, a slight reduction of airspeed, the release of back pressure on the cyclic stick, or by reducing the severity of the maneuver.

APPENDIX A. REFERENCES

1. Letter, AVRADCOM, DRDAV-EQI, 26 October 1977, subject: Preliminary Airworthiness Evaluation, CH-47C with Fiberglass Rotor Blades.
2. Military Specification, MIL-L-8501A, *Helicopter Flying and Ground Handling Qualities, General Requirements For*, 7 September 1961, with amendment 1, 3 April 1962.
3. Specification, Boeing Vertol Company, No. D210-11100-1, *System Specification with Fiberglass Reinforced Composite Rotor Blades*, 7 May 1976.
4. Technical Manual, TM 55-1520-227-10-2, *Operator's Manual, Army Model CH-47C Helicopter*, 23 August 1978.
5. Final Report, USAASTA, Project No. 66-28, *Army Preliminary Evaluation III and IV, YCH-47C Medium Transport Helicopter*, July 1970.
6. Final Report, USAAEFA, Project No. 66-29, *Airworthiness and Flight Characteristics Test, CH-47C Helicopter (Chinook), Performance*, September 1971.
7. Final Report, USAAEFA, Project No. 66-29, *Airworthiness and Flight Characteristics CH-47C Helicopter (Chinook), Stability and Control*, March 1972.
8. Letter, AVRADCOM, DRDAV-EQI, 27 October 1978, subject: Airworthiness Release for CH-47C Helicopter S/N 74-22287 with Fiberglass Rotor Blades, USAAVRADCOM/USAAEFA Project 77-31.
9. Flight Test Manual, Naval Air Test Center, FTM No. 102, *Helicopter Performance Testing*, 28 June 1968.
10. Flight Test Manual, Naval Air Test Center, FTM No. 101, *Helicopter Stability and Control*, 10 June 1968.
11. Letter Report, Acoustical Research Branch, Engineering Research Laboratory, US Army Human Engineering Laboratories, No. 95, *Interior Noise Evaluation of the CH-47C Helicopter*, January 1969.
12. Letter Report, USAAEFA, Project No. 77-29, *Airworthiness and Flight Characteristics Evaluation, CH-47C Helicopter with T55-L-712 Engines*, 16 March 1978.
13. Specification, The Boeing Company, Vertol Division, No. 114-PJ-803, *Detail Specification for the Model CH-47C Helicopter*, 7 December 1967, with Revision A, 15 May 1969.

APPENDIX B. AIRCRAFT DESCRIPTION

GENERAL

1. The test aircraft was a standard CH-47C with the modifications listed below. Photo 1 shows the test aircraft and fiberglass blades. Photos 2 through 5 show the cockpit arrangement.

- a. 114R1702 fiberglass rotor blades in lieu of standard metal blades.
- b. Calibrated/instrumented T55-L-712 engines.
- c. Cockpit self-tuning vibration absorbers tuned at 220 to 240 rpm with mass increased to 95 pounds.
- d. Aft pylon fixed tune vibration absorbers removed.
- e. Pitch links on forward head replaced with steel links. (similar to aft head)
- f. Forward transmission cover actuator mount lugs bored and shot peened.
- g. Modified swiveling actuator lower mount bearing and attachment hardware.
- h. Rotor hub assembly lightning protection provisions.
- i. Airspeed trim amplifier box modified to supply altitude bias to the aft longitudinal cyclic trim (LCT) actuator (in addition to the forward LCT actuator).

ROTOR BLADES

2. The fiberglass rotor blade radius is 30 feet, the same as for the B and C models. The blade chord was increased from 25.25 inches to 32 inches. The planform is constant-chord between blade station 97 and 360; from blade station 97 inboard it transitions to a circular root end section. The airfoil is changed; in place of the 23010 airfoil of the B and C models, the fiberglass blades have a 12% thick VR-7 airfoil out to 85% radius, tapering uniformly to an 8% thick VR-8 at the tip. Twist is -12 degrees. The blade is designed to operate at a constant 225 rpm. Structurally, the blade has a composite D-spar with a precured heel covered by a titanium cap and, on the outer 30% of radius, a replaceable nickel erosion cap. The aft section of the blade is Nomex honeycomb covered with a glass fiber skin cross-plyed at 45 degrees to the longitudinal axis of the blade. The root of the blade is formed of unidirectional glass fiber straps wrapped around the root fitting. The blade nose block has a balance weight; at the tip there is a set of removable tungsten tracking weights accessed through a bolted-on coverplate. A diagram of the blade is presented in figure 1.



Photo 1. CH-47C With Fiberglass Rotor Blades.



Photo. 2. Pilot's Station.



Photo 3. CoPilot's Station.

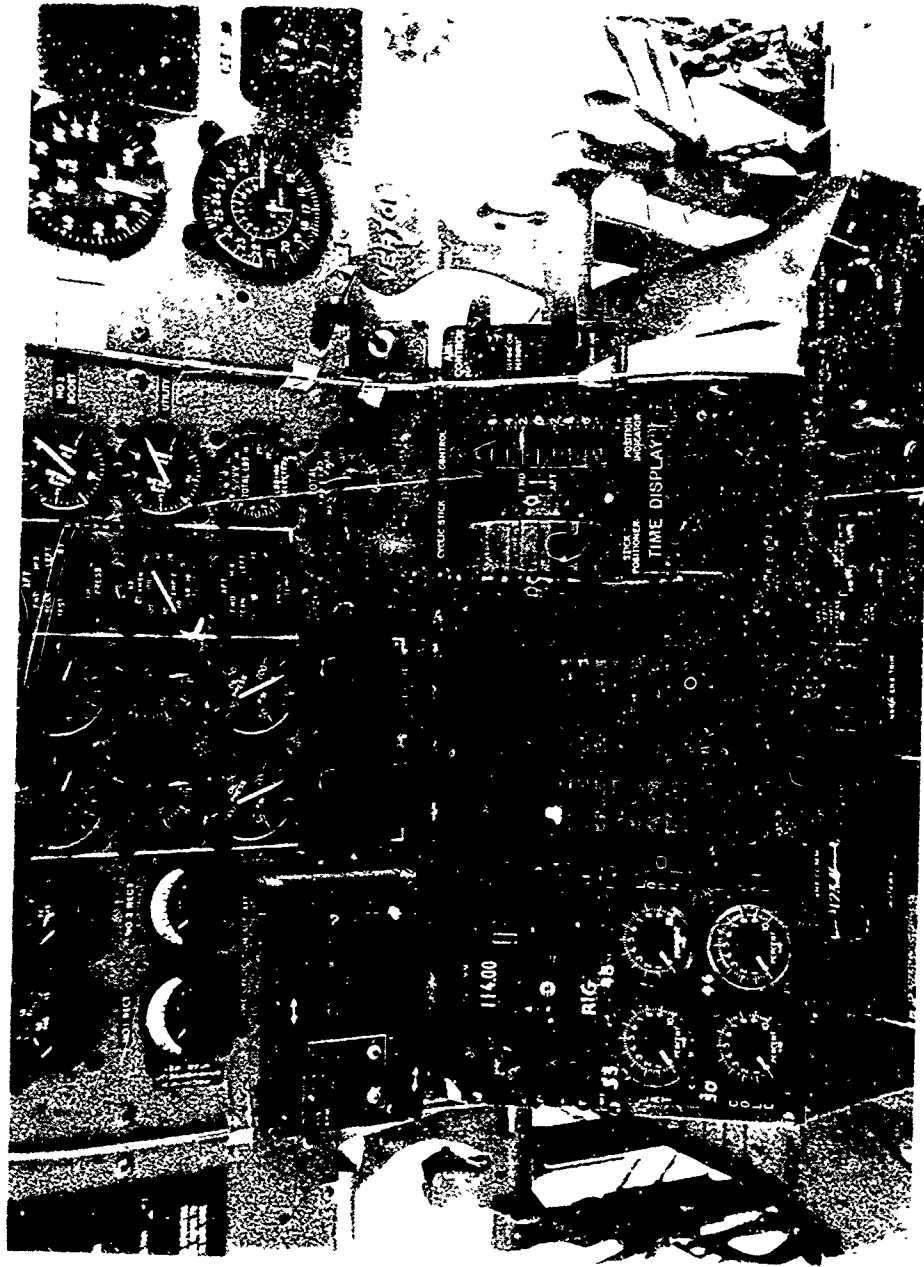


Photo 4. Console

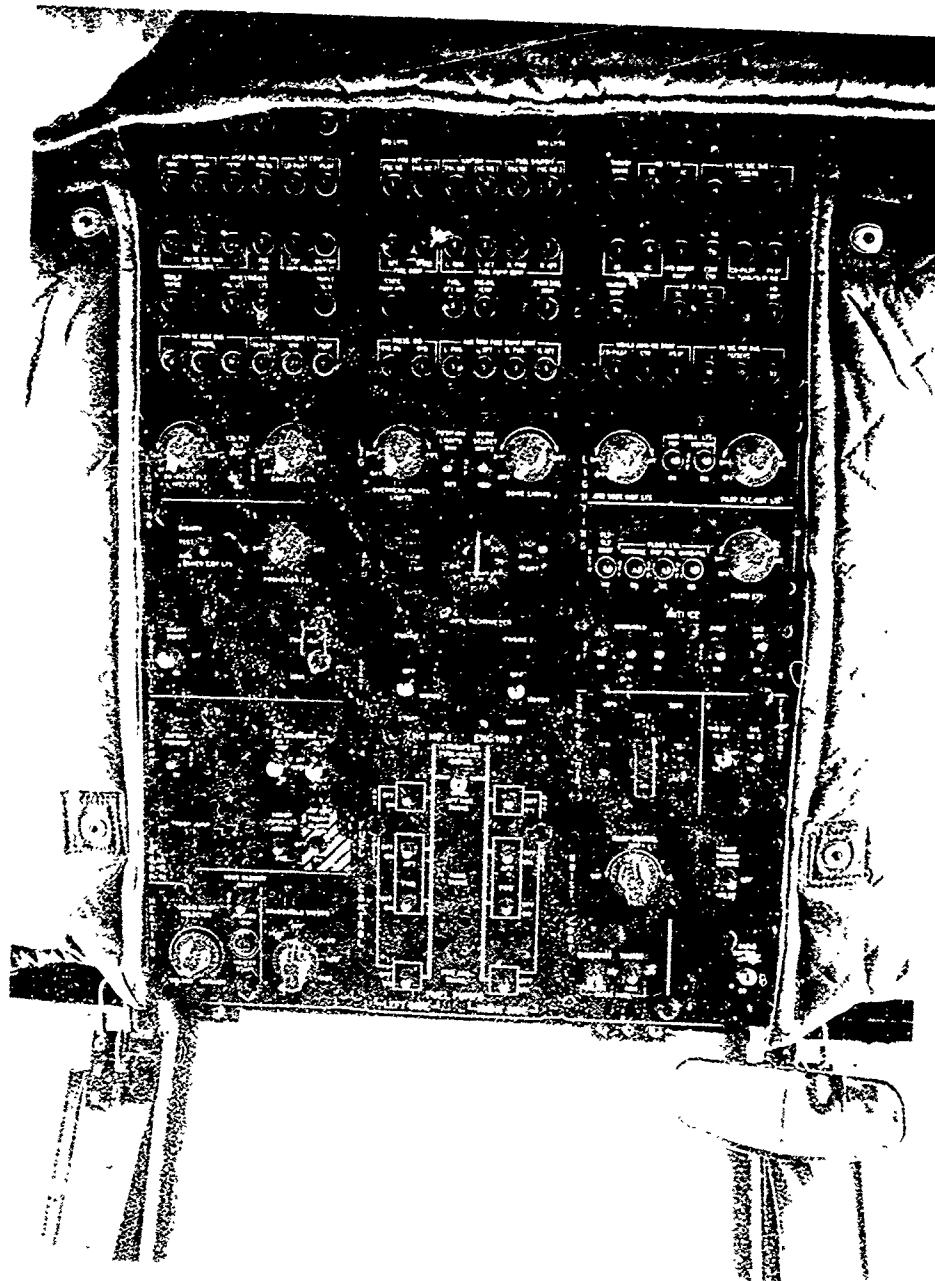


Photo 5 Overhead Panel

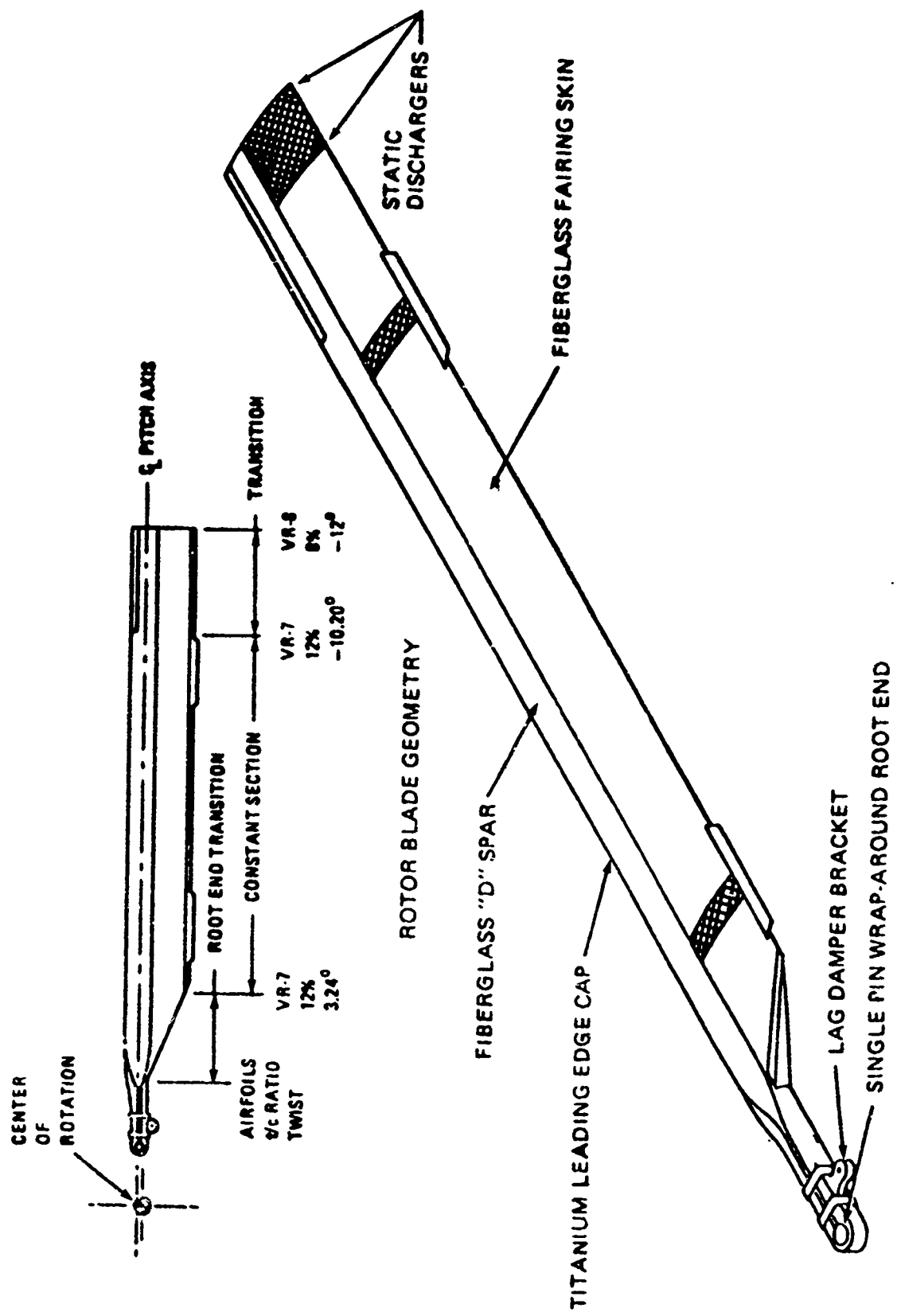


Figure 1. CH-47C Fiberglass Rotor Blade.

GENERAL AIRCRAFT INFORMATION

DIMENSIONS

Length (Fuselage)	51 ft
Length (rotor blades turning)	99 ft
Height (over rotor blades at rest)	18 ft, 7.8 in.
Width of cabin	9 ft
Tread (forward gear)	10 ft, 6 in.
Tread (aft gear)	11 ft, 2 in.
Width (rotor blades turning)	60 ft

WEIGHT DATA

Empty weight (specification)	21,722 lb
Design gross weight	33,000 lb
Alternate design gross weight	46,000 lb

CENTER-OF-GRAVITY REFERENCE

3. Center-of-gravity limits for the purposes of this test were expanded from the standard CH-47C limits and are shown in figure 2.

Center-of-gravity reference	FS 331.0 (centerline between rotors)
Forward limit (from cg reference)	21.0 in. forward (28,500 lb and below)
Aft limit (from cg reference)	18.0 in. aft (28,500 lb and below)

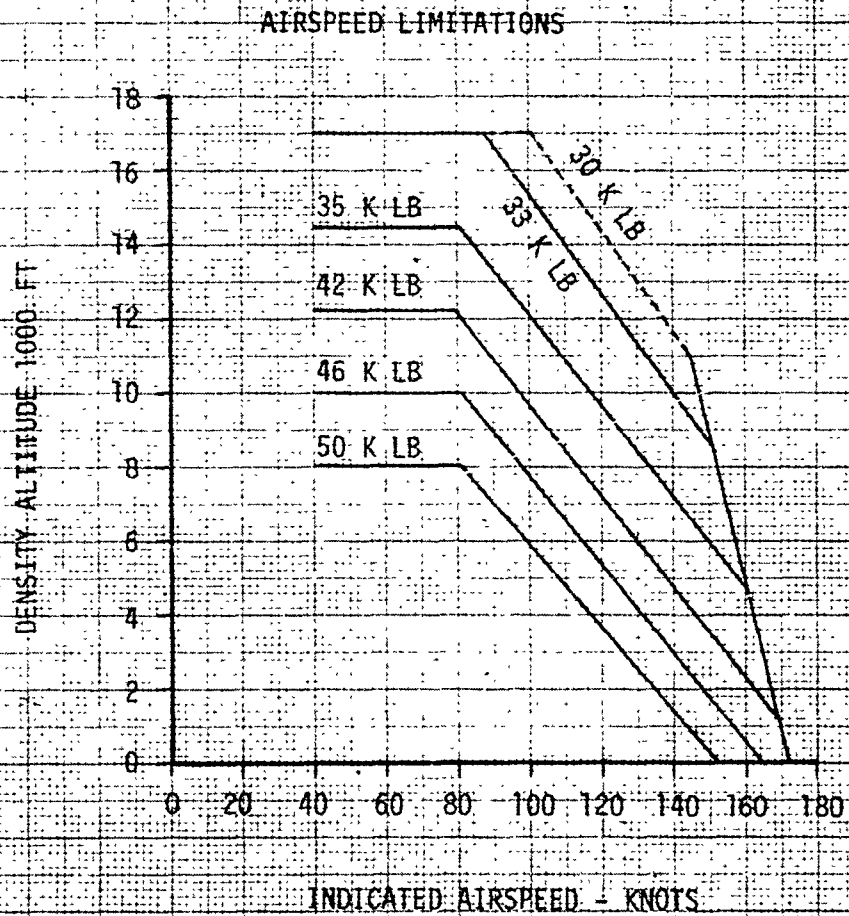
T55-L-712 ENGINE

Emergency power	4500 shp
Maximum power	3750 shp
Military rated power	3400 shp
Normal rated power	3000 shp

AREAS

Rotor blade area (6 at 80 sq ft)	480 sq ft
Projected disc area	5000 sq ft
Swept disc area (2 rotors at 2827 sq ft used in performance calculations)	5654 sq ft
Geometric solidity ratio	0.085
Sail area (cross-section area of aircraft at butt line zero)	487 sq ft

FIGURE 2
CH-47C WITH FIBERGLASS ROTOR BLADES



DIMENSIONS AND GENERAL DATA

Rotor spacing (distance between center line of rotors)	39 ft, 2 in.
Sail area centroid	FS 367.5 water line 28.6
Rotor blade clearance:	
Ground to tip (forward rotor static)	7 ft, 10.6 in.
Leading edge of aft pylon to forward rotor blade tip (rotor blade static)	16.7 in.
Leading edge of aft pylon to forward rotor blade tip (rotor turning)	40 in.
Rotor Data:	
Power loading at alternate design gross weight (46,000/6,000)	7.67 lb/hp
Blade droop stop angle:	
Aft rotor	1.5 deg
Forward rotor	4.75 deg
Blade coning (stop angle)	30 deg
Blade twist (centerline of rotor to tip)	-12 deg (fig. 1)
Rotor diameter	60.0 ft
Rotor speed normal operation	225 rpm
Power ON maximum	240 rpm
Power OFF maximum	245 rpm
Power ON or OFF minimum	212 rpm
Number of blades (each rotor)	3
Airfoil section designation and thickness	VR-7 to 85% radius tapered to VR-8 at tip (fig. 2)
Aerodynamic chord (root and tip)	32.00 in.

GENERAL FLIGHT CONTROL DESCRIPTION

4. The flight control system is irreversible and is powered by two independent hydraulic boost systems, each operating at a 3000-psi pressure. Operation of the helicopter is not possible unless one of the boost systems is in operation.

CONTROL SURFACES

Type of Control Surfaces

5. The movable control surfaces consist of six main rotor blades, three mounted on each rotor head. The forward and aft rotor heads are in tandem along the longitudinal axis of the helicopter. The forward rotor blades are individually interchangeable and the aft rotor blades are individually interchangeable. The rotor heads are fully articulated, which permits blade movement about the pitch, flap, and lead/lag axes. The airfoil section is a VR-7 out to 85% radius, tapering uniformly to a thin tip VR-8.

Limits of Control Travel

6. The allowable pitch change movements of the control surfaces are described in table 1.

Control Functions

7. In the tandem rotor configuration, control about all axes is achieved through combinations of cyclic and collective pitch variations on the forward and aft rotor systems.

Longitudinal

8. The helicopter is controlled longitudinally through application of differential collective pitch (DCP) by fore and aft movement of the cyclic control. Collective pitch on the forward rotor is decreased, while collective pitch on the aft rotor is increased to provide nose-down pitch. The opposite occurs for nose-up movement.

Table 1. Allowable-Pitch Change Movements.

Control	Blade Pitch (deg)
Longitudinal control (differential collective blade pitch)	±4
Lateral cyclic blade pitch	±8
Directional control (differential lateral cyclic blade pitch)	±11.43
Thrust control rod pitch	1 to 18
Maximum simultaneous directional plus lateral control	16.5 forward rotor 16.5 aft rotor
Stick trim (wheel) Speed trim PSAS	±0.615 of DCP ±0.769, -0. ±0.615
Longitudinal cyclic speed trim	±1/2 aft forward rotor both rotors ±to 40 fwd aft rotor

Lateral

9. Both rotor planes are tilted in the desired direction of turn by cyclic variation of blade pitch angle through left or right movement of the cyclic control stick.

Directional

10. The rotor planes are tilted laterally in opposite directions through application of the directional control pedals. During turns to the left the forward rotor tilts left, while the aft rotor tilts to the right. The opposite occurs during turns to the right.

Vertical

11. The collective pitch on the fore and aft rotors is changed by an equal amount to effect altitude changes by application of the thrust control rod.

COCKPIT CONTROLS

Limits of Cockpit Control Travel

12. The limits of cockpit control movement are shown in table 2.

Control Centering and Feel

13. Flight control feel is introduced artificially through the use of centering springs and magnetic brakes connected to the flight bell cranks and control rods. When a switch on either cyclic control grip is depressed, the longitudinal, lateral, and directional centering devices are released and allow the cyclic control and directional pedals to be repositioned to obtain a new flight attitude and corresponding control position. Releasing the switch removes electrical power which applies the magnetic brakes and reengages the centering springs with the controls positioned in the new center of reference. With the pitch stability augmentation system (PSAS) installed when either of the centering device switches are depressed, the PSAS is deactivated

Table 2. Cockpit Control Limits.

Control	Total Control Travel (in.)
Longitudinal cyclic	6.85 aft to 7.05 fwd
Lateral cyclic	4.45 left to 4.0 right
Directional pedal	3.8 left to 4.25 right
Thrust control rod	9.6

if the PITCH STAB AUG switch is at AUTO SYNC or NORMAL SYNC. The artificial feel centering device springs on all controls may be manually overcome at any time; however, when control pressure is released, the controls will return to their original position. A trigger-type switch on each thrust control rod grip controls a magnetic brake that holds the thrust control rod in place when no movement is desired.

Longitudinal Control Positioner

14. A longitudinal control positioning wheel is installed to allow the pilot to position the cyclic fore and aft to compensate for various cg conditions. No motions are imparted by the trim wheel to the flight control system and the wheel is not capable of aerodynamically trimming the helicopter.

STABILITY AUGMENTATION SYSTEM

15. Two complete stability augmentation systems (SAS) are installed in the CH-47C helicopter. The system is designed so that both SAS are used simultaneously with each operating at half gain. During dual operation, if a single SAS failure occurs, the operating SAS automatically functions at full gain, producing no significant change in control feel or response. The SAS automatically maintains stability about the pitch, roll, and yaw axes and functions to permit coordinated (cyclic only) turns at airspeeds above 40 KIAS. The SAS channels receive bank angle signals from the vertical gyros. Limited roll attitude stability is provided for bank angles up to 5 degrees in either direction. The basic components of the SAS are three dual extensible links, two SAS amplifiers, three gyros for sensing angular rates, pressure transducers used for sensing sideslip, and various control switches and caution lights. Corrective signals from each gyro or sensor are fed into the control system differentially through the SAS extensible links, whereby the rotor head controls move without producing movement of the cockpit controls. By this method, the requirement for only limited control authority is possible. The pilot can override a malfunctioning SAS should a hardover signal occur.

DIFFERENTIAL COLLECTIVE PITCH TRIM

16. A fully automatic DCP trim system is incorporated in the flight control system to improve longitudinal control position characteristics with airspeed. The DCP actuators program aft differential collective pitch with increasing airspeed and forward differential collective pitch with decreasing airspeed. The basic components of the DCP trim system are the DCP actuator, the airspeed trim amplifier, and the pitot system. The DCP trim system converts airspeed information from the pitot system through the airspeed trim amplifier to an electrical signal which controls extension or retraction of the DCP actuator. The DCP trim system is automatically programmed between 40 and 160 KIAS.

LONGITUDINAL CYCLIC SPEED TRIM

17. A longitudinal cyclic airspeed trim system which can be operated either manually or automatically is incorporated in the flight control system. The longitudinal cyclic airspeed trim system reduces the angle of attack of the fuselage relative to the

airstream as forward airspeed is increased, thus reducing fuselage drag. The system also reduces rotor blade flapping, which results in lower stresses in the rotor shafts. A longitudinal cyclic airspeed trim actuator is installed under each of the swashplates. Signals are automatically transmitted to these actuators by either the airspeed trim amplifier (control box) or by pilot-command signals from the manual longitudinal cyclic airspeed trim switches on the onsole. The cyclic trim indicators are mounted on the center instrument panel, and the control switches are located on the console. Both forward and aft actuators on the CH-47C with fiberglass blades receive an altitude bias signal from the airspeed trim actuator box.

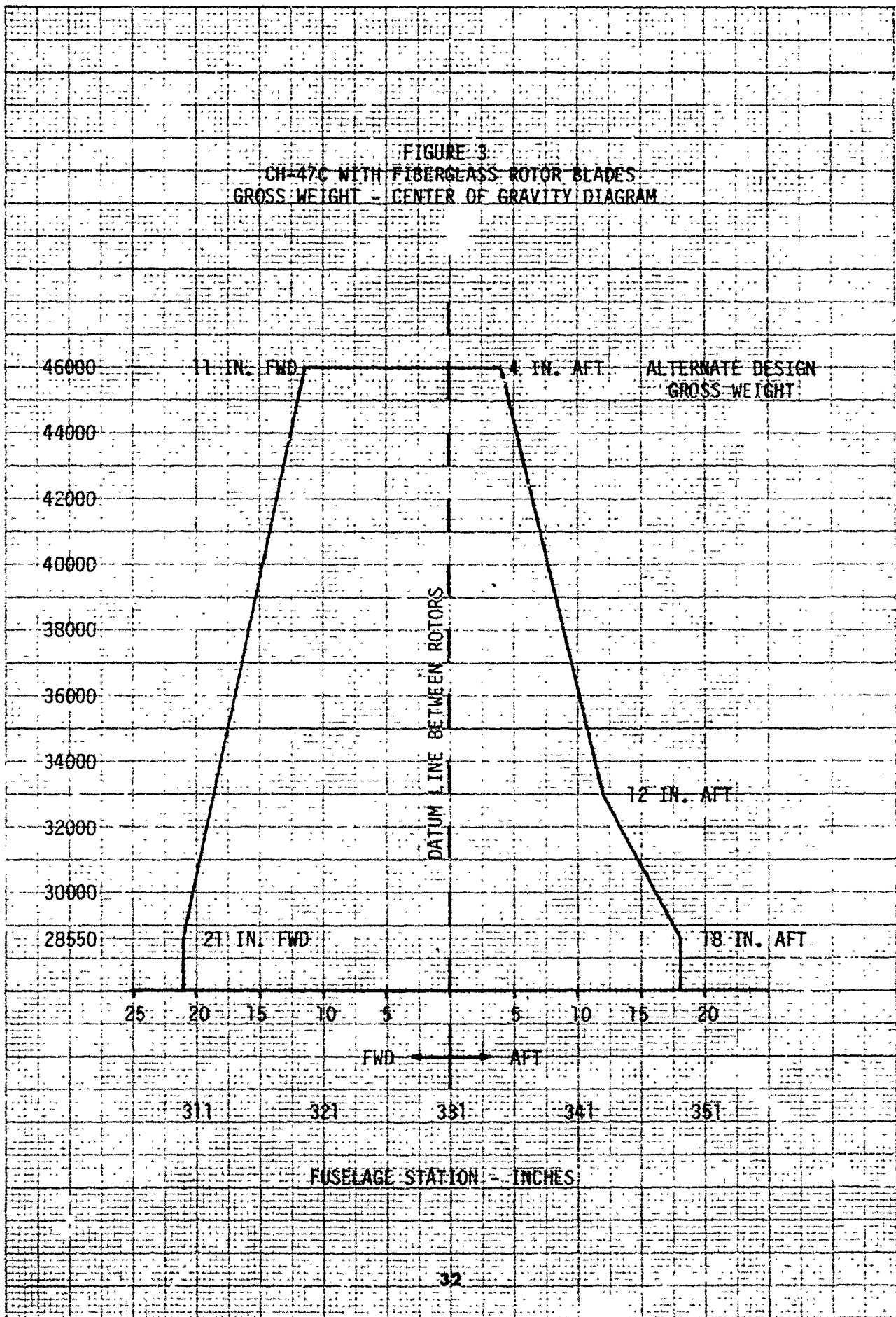
PITCH STABILITY AUGMENTATION SYSTEM

18. A PSAS is incorporated into the flight control system to improve airspeed and pitch stability. The copilot vertical gyro and the pitot system provide inputs, through the airspeed trim amplifier, to the DCP trim actuator when operating in the NORMAL or AUTO SYNC mode. The CH-47C is equipped with a three-position (OFF/NORMAL/AUTO) PSAS mode selection switch. The NORMAL mode provides a continuous signal, equivalent to 0.13 inch of longitudinal cyclic per degree of pitch attitude change and 0.07 inch of longitudinal cyclic per knot of airspeed change about trim, to the DCP, regardless of the cyclic control position. In the AUTO mode, the PSAS operates in the same manner as the NORMAL mode, providing that the cyclic is not moved more than 1/8 inch forward or aft of its trim position. Motion beyond these limits causes automatic deactivation of the PSAS. Longitudinal static and dynamic stability is then provided only by the SAS.

AIRSPPEED ENVELOPE

19. The airspeed envelope (V_{ne}) as a function of altitude and weight used during the test program is presented as figure 3.

FIGURE 3
 CH-47C WITH FIBERGLASS ROTOR BLADES
 GROSS WEIGHT - CENTER OF GRAVITY DIAGRAM



APPENDIX C. INSTRUMENTATION

GENERAL

1. Test instrumentation was installed, calibrated, and maintained by the contractor. Data was displayed in the cockpit, recorded on on-board magnetic tape, and relayed via telemetry to STARLAB at the contractor facility where real time observation and recording of parameters was monitored by the project engineer. Cockpit arrangement is shown in photos 2 through 6, appendix B. Photos 1 and 2 of this appendix show the instrumentation package. Photo 3 shows the ballast boxes installed for heavy gross weight operations.

2. Instrumentation for the test is listed below. An asterisk preceding the parameter indicates a cockpit display as well as being recorded on magnetic tape.

- *Airspeed (production)
- *Airspeed (boom)
- *Altitude, pressure (production)
- *Ambient air temperature
- *Rotor speed (sensitive scale)
- *Event marker
- 1/rev signal (fwd)
- Control position:
 - *Longitudinal
 - *Lateral
 - *Collective
 - *Directional
- *Sideslip angle
- Attitude:
 - Pitch
 - Roll
 - Yaw
- Rate:
 - Pitch
 - Roll
 - Yaw
- *Fuel totalizer (No. 1 and No. 2)
- Fuel flow (No. 1 and No. 2)
- Fuel temp. (No. 1 and No. 2)
- *Engine torque (No. 1 and No. 2)
- *Time
- *Record counter
- *Cyclic trim (fwd)
- *Cyclic trim (aft)
- *Rotor speed (coarse scale)
 - SAS position (No. 1 and No. 2)
 - Pitch Roll
 - Pitch Yaw
- DCP airspeed trim position
- Longitudinal stick positioner actuator position

*Engine condition level position (No. 1 and No. 2)

*Engine N1 (No. 1 and No. 2)

*Turbine inlet temperature (No. 1 and No. 2)

Center-of-gravity acceleration:

*Vertical (sta 360, BL 0, WL 30)

*Lateral (sta 360, BL 0, WL 30)

*Longitudinal (sta 360, BL 0, WL 30)

Tether cable angle:

*Longitudinal

*Lateral

*Tether cable load-axial

Aft rotor torque (3 channels)

Fwd rotor torque (3 channels)

Fwd shaft bending (6 positions)

Aft shaft bending (8 positions)

*Droop stop contact lights

*Cruise guide indicator

Vibrations (accelerometer location):

FS 95 center line (vertical, lateral, longitudinal)

Pilot and copilot right heel slide (vertical)

FS 50 left and right (vertical)

FS 320 butt line 25 and 44 left and right (vertical)

FS (vertical, lateral, longitudinal) 482 butt line 44 left and right

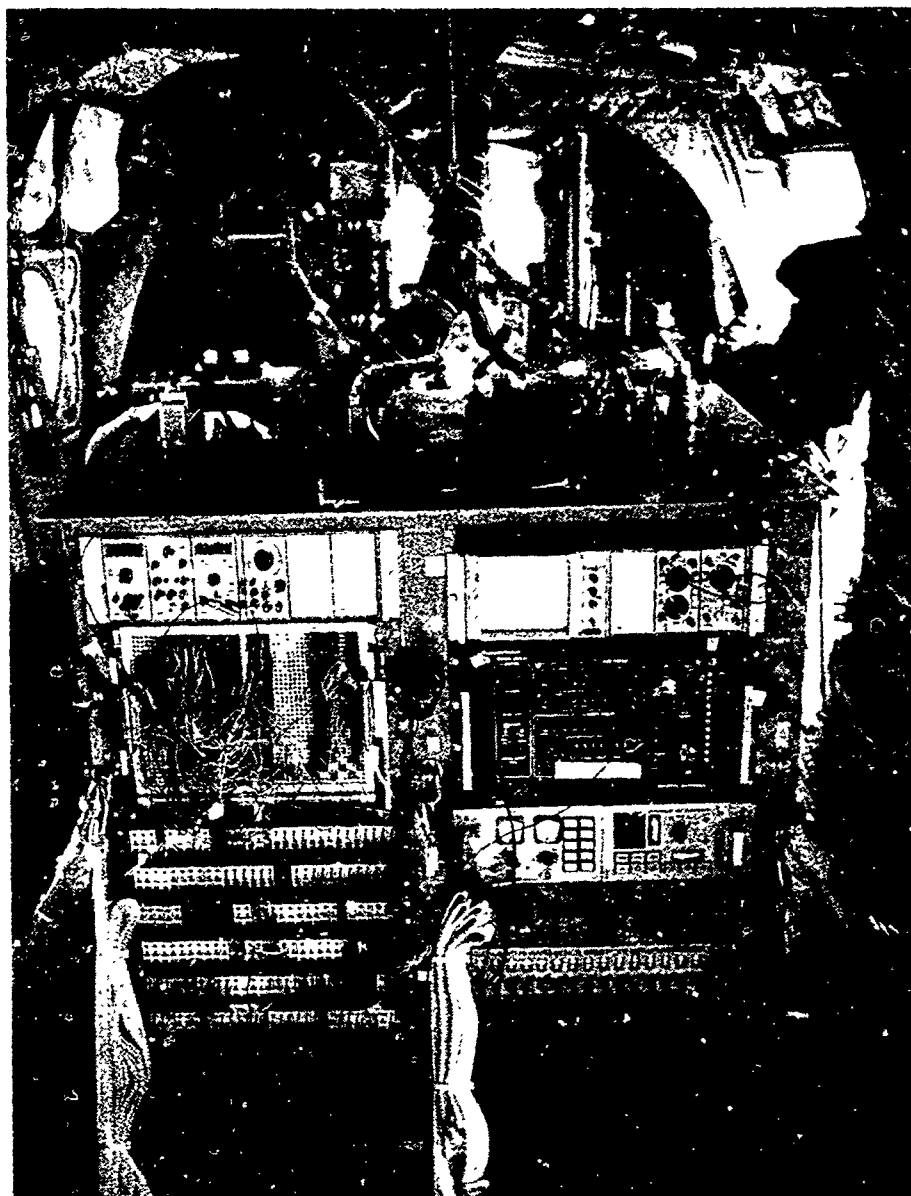


Photo 1. Instrumentation Package Forward.

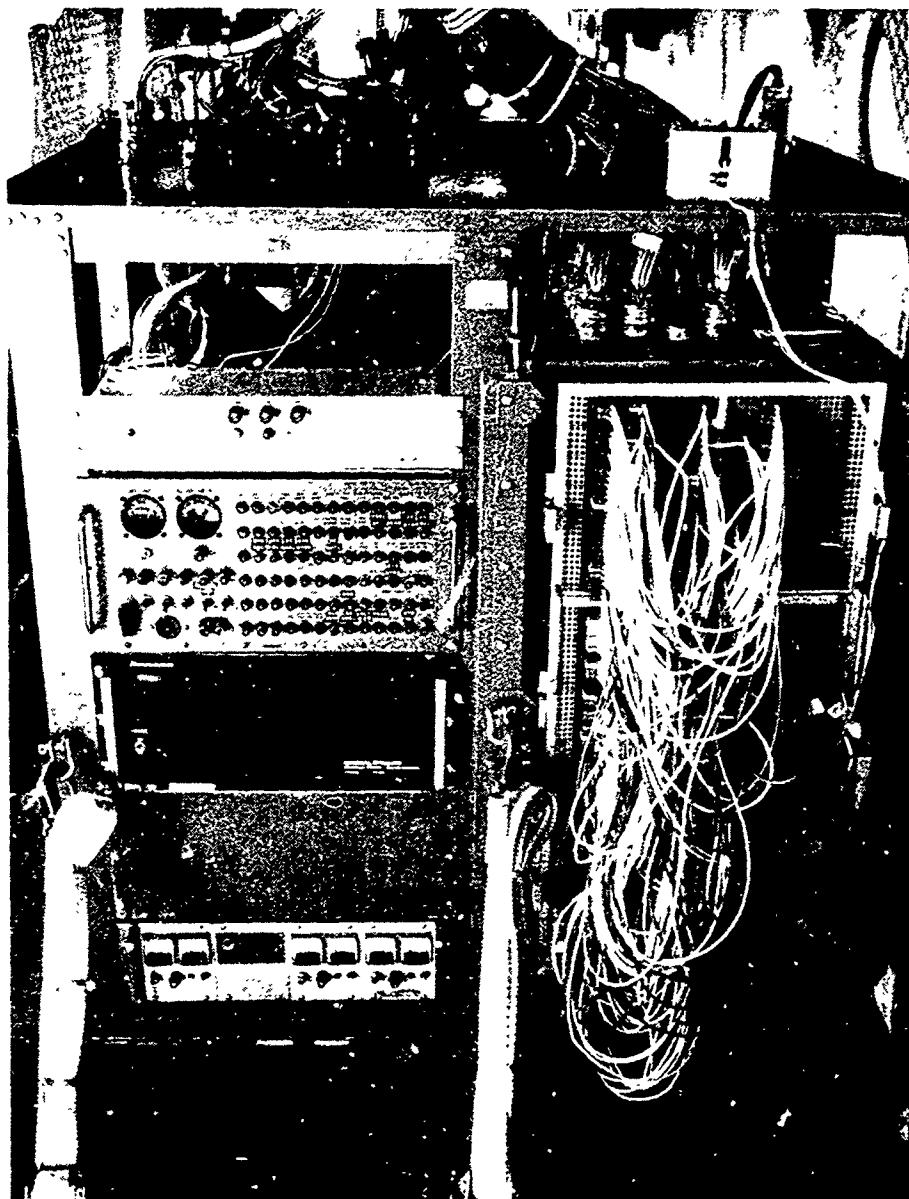


Photo 2. Instrumentation Package Aft.

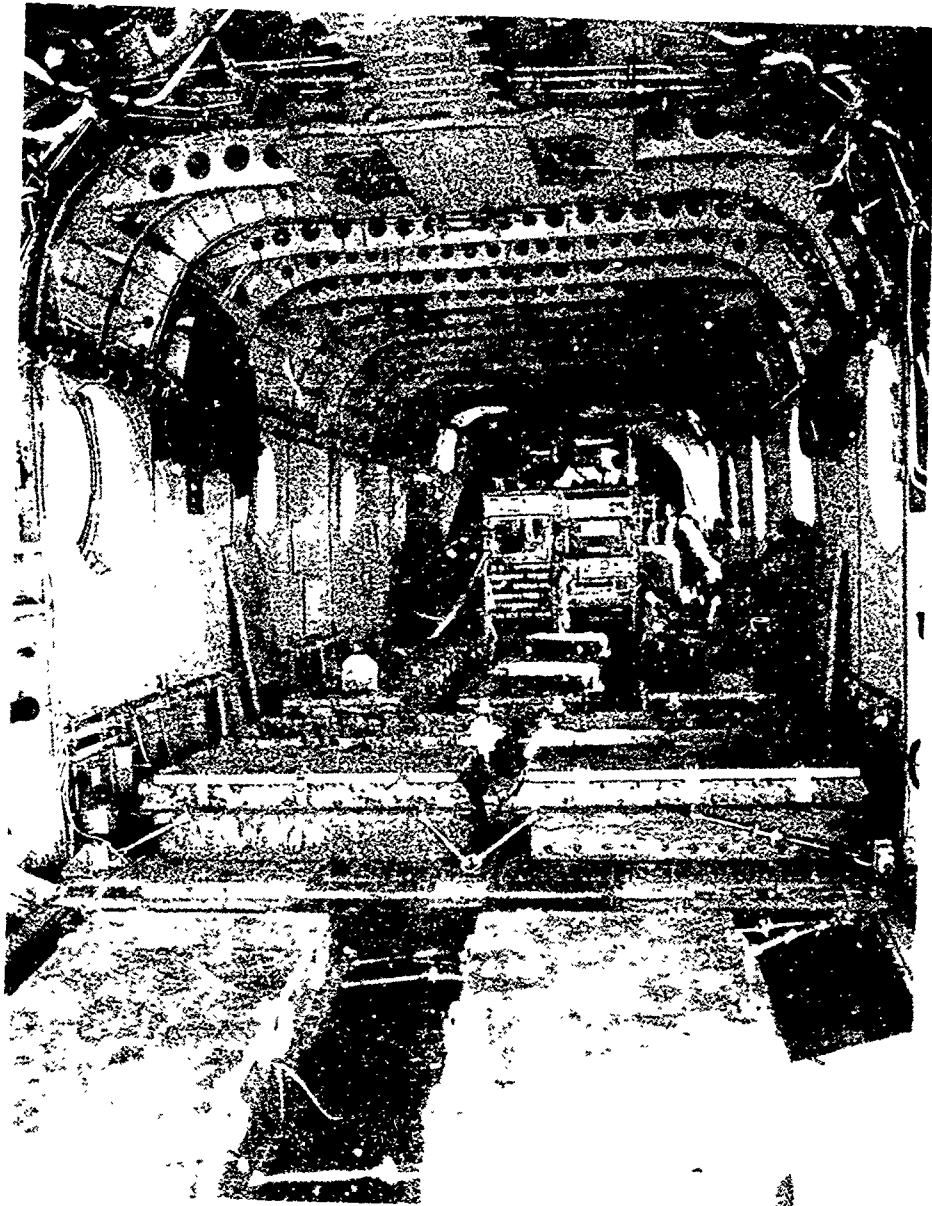


Photo 3. Cabm With Ballast Configuration.

APPENDIX D. TEST TECHNIQUES AND DATA ANALYSIS METHODS

NONDIMENSIONAL COEFFICIENTS

1. The nondimensional coefficients listed below were used to generalize the hover and level flight data obtained during this evaluation.

- a. Coefficient of power

$$C_P = \frac{\text{SHP} \times 550}{\rho A (\Omega R)^3}$$

- b. Coefficient of thrust

$$C_T = \frac{W}{\rho A (\Omega R)^2}$$

- c. Advancing blade tip mach number (M_{tip})

$$M_{\text{tip}} = \frac{1.6878 V_T + (\Omega R)}{a}$$

Where:

SHP = Output shaft horsepower

550 = Conversion factor (ft-lb/sec/shp)

ρ = Air density (slug/ft³)

A = Main rotor disc area (ft²)

Ω = Main rotor angular velocity (radian/sec) = $\frac{\pi}{30}$ x RPM

R = Main rotor radius (ft)

W = Aircraft gross weight (lb)

V_T = True airspeed (kt)

a = Speed of sound (ft/sec - $1116.45\sqrt{\theta}$)

1.6878 = Conversion factor (ft/sec/kt)

θ = Temperature ratio = $\frac{(\text{OAT} + 273.15)}{288.15}$

POWER DETERMINATION

2. The method of determining engine output shaft horsepower from calibrated engine torquemeters was not used for this program because of previous experience with torquemeter inconsistency and inaccuracies. For these tests, output shaft horsepower for the T55 engine was determined by two methods: measured fuel flow and rotor torque. Both fuel flow and rotor torque were recorded on PCM tape. The fuel flow parameters utilized the Lycoming test stand engine calibration curve with the Boeing Computer Services (BCS) CH-47 Real Time Performance Program to determine referred shaft horsepower. The rotor torque parameters also utilized the BCS CH-47 Real Time Performance Program to determine referred rotor horsepower using the rotor horsepower. Total shaft horsepower using the rotor torque was determined by adding a constant transmission and accessory loss (180 shp) to the recorded value.

$$\text{SHP} = \text{RHP}_{\text{fwd rotor}} + \text{RHP}_{\text{aft rotor}} + 180$$

A comparison of the fuel flow and rotor torque calculated shaft horsepower revealed that an inconsistency existed during the hover performance tests. The PAE hover rotor torque calculated horsepower agreed with Boeing Vertol (B-V) rotor torque and fuel flow data. The PAE fuel flow horsepower was consistently higher than the PAE recorded rotor torque and the B-V fuel flow and rotor torque data. Since the PAE recorded rotor torque hover data agreed with both the B-V rotor torque and fuel flow data, all performance data were determined utilizing referred rotor horsepower. Test results were compared to the results of USAAEFA Report No. 66-29 (ref 5, app A), which used engine torque derived from fuel flow for power determination. To reconcile the inconsistencies between PAE fuel flow and rotor torque measured powers the engines were returned to Lycoming for recalibration. Post test recalibration showed engine deterioration of approximately 3.5 percent, which when applied to fuel flow data gave excellent agreement between fuel flow and rotor torque methods of determining power.

HOVER

3. Hover performance was obtained both IGE and OGE by the tethered hover technique. All hover tests were conducted in winds of less than 3 knots. Atmosphere pressure, temperature, and wind velocity were recorded from a ground weather station. The tethered hover tests consisted of stabilizing the helicopter with cable attached at predesignated rotor speeds and power settings. The power setting was varied from the minimum required to maintain cable tension to the maximum allowed for cable tension and aircraft weight to equal the maximum gross weight of the CH-47C. Rotor speed was varied from 220 to 240 rpm in 5-rpm increments. All hover data were reduced to the nondimensional parameters of C_p and C_T . These data are presented in figures 1 and 2, appendix E.

LEVEL FLIGHT

4. Level flight speed-power performance was determined using referred gross weight, shaft horsepower, and true airspeed. Each speed-power polar was flown maintaining a constant referred gross weight (W/δ) and referred rotor speed ($N/\sqrt{\theta}$). A constant W/δ was maintained by decreasing ambient pressure ratio (δ), increasing altitude as the aircraft gross weight decreased due to fuel burnoff. Rotor speed was also varied to maintain a constant $N/\sqrt{\theta}$ as the outside air temperature varied.

Where:

W/δ = weight divided by pressure ratio

5. The raw data were reduced to referred terms: $SHP/\delta\sqrt{\theta}$, $V_T/\sqrt{\theta}$, W/δ , and $N/\sqrt{\theta}$. Each point was then corrected to unaccelerated flight, zero rate of climb, aim W/δ , aim $N/\sqrt{\theta}$, and equivalent flat plate area due to nonproduction aircraft configuration. Adjustments to the forward flight data were made to properly account for the configuration differences which existed between the test aircraft and a standard CH-47C. These differences represented a total drag increase of 4.16 ft^2 , as defined below.

<u>Item</u>	<u>Flat Plate Area (ft²)</u>	<u>Data Basis</u>
Rotor packages	3.30	Wind Tunnel Test
Airspeed nose boom	0.32	Estimated
Forward gear position instrumentation	0.54	Estimated

The airspeed boom and gear potentiometer drag are estimated values, while the rotor package drag is based on the 1/8 scale model test. A 100% propulsive efficiency was assumed when converting drag to power. The data reduction and corrections were performed utilizing the B-V CH-47 Real Time Performance Program.

CONTROL POSITIONS IN TRIMMED FORWARD FLIGHT

6. Control positions and aircraft attitudes as functions of airspeed were determined during level flight performance.

STATIC LONGITUDINAL STABILITY

7. The static longitudinal stability tests were accomplished by establishing the trim condition and then varying longitudinal control positions to obtain airspeed changes about the trim airspeed with collective control held fixed. The airspeed range of interest was approximately ± 20 knots from trim. Altitude was allowed to vary as required during the test. Static longitudinal stability was repeated in a steady-state climb and autorotational descent at 60 KCAS.

STATIC LATERAL-DIRECTIONAL STABILITY

8. These tests were conducted by establishing the trim condition and then varying sideslip angle incrementally up to the limits of the sideslip envelope or until full directional control up to the limits of the sideslip envelope or until full directional control was reached. During each test, collective control position, airspeed, and aircraft ground track were held constant and altitude allowed to vary as required.

MANEUVERING STABILITY

9. The tests were accomplished by establishing the trim condition and then incrementally increasing load factor by increasing roll attitude (in both directions) while holding airspeed and collective control position constant.

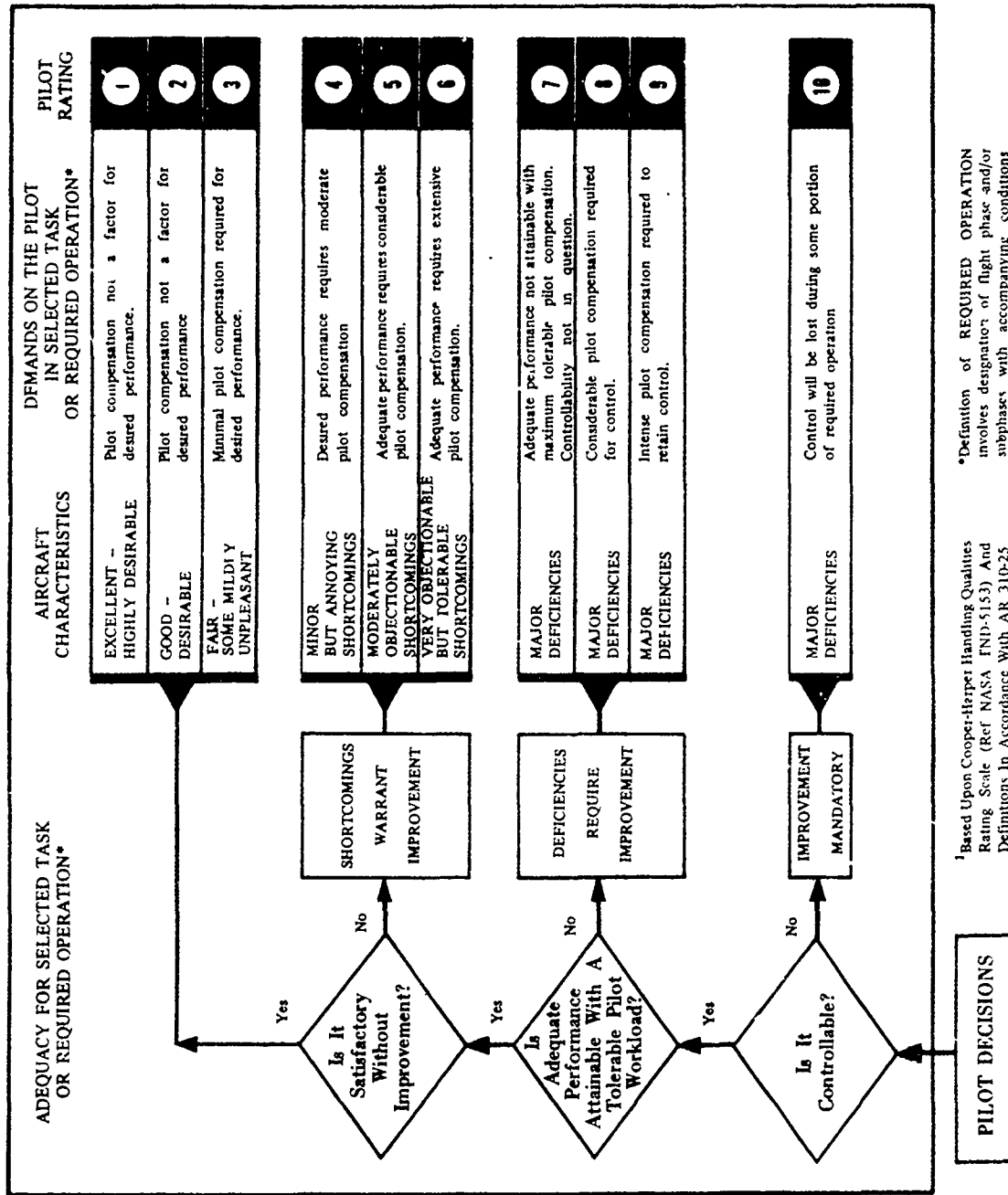
DYNAMIC STABILITY

10. Dynamic longitudinal and lateral-directional stability were qualitatively evaluated to determine both the short- and long-period characteristics. The short-period response was evaluated by use of longitudinal and lateral cyclic and directional pulse inputs to all flight controls in both directions. The long-period dynamic response was evaluated by slowly returning the flight controls to trim position following a decrease of 10 knots indicated airspeed (KIAS) from the trim airspeed and by a release from a steady-heading sideslip.

CONTROLLABILITY

11. Controllability tests were accomplished by applying longitudinal, lateral and Directional step inputs of three magnitudes (approximately 1/4, 1/2, and 1 inch in both directions) were evaluated. The step input was made by rapidly displacing the control (less than 0.1 second) from trim, against a control fixture. The input was held until a steady-state rate was obtained or recovery was necessary. All controls, other than the input control, remained fixed. In forward flight, at both 60 and 120 KCAS., the inputs were initiated during unaccelerated ball-centered level flight. The hover controllability test was conducted in winds of 3 knots or less, at a rear wheel height of 30 feet.

12. A Handling Qualities Rating Scale was used to augment pilot comments and is presented as figure 1. The Vibration Rating Scale (VRS) was used to augment pilot comments on vibrations and is presented as figure 2.



*Based Upon Cooper-Harper Handling Qualities Rating Scale (Ref NASA TN-D-5153) And Definitions In Accordance With AR 310-25

*Definition of REQUIRED OPERATION involves designation of flight phase and/or subphases with accompanying conditions

Figure 1. Handling Qualities Rating Scale.

DEGREE OF VIBRATION	DESCRIPTION ¹	PILOT RATING
No vibration		0
Slight	Not apparent to experienced aircrew fully occupied by their tasks, but noticeable if their attention is directed to it or if not otherwise occupied.	1 2 3
Moderate	Experienced aircrew are aware of the vibration but it does not affect their work, at least over a short period.	4 5 6
Severe	Vibration is immediately apparent to experienced aircrew even when fully occupied. Performance of primary task is affected or tasks can only be done with difficulty.	7 8 9
Intolerable	Sole preoccupation of aircrew is to reduce vibration level	10

¹ Based upon the Subjective Vibration Assessment Scale developed by the Aeroplane and Armament Experimental Establishment, Boscombe Down, England.

Figure 2. Vibration Rating Scale.

APPENDIX E. TEST DATA

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Airspeed Calibration	26

FIGURE 1
NON-DIMENSIONAL HOVER PERFORMANCE
 CH-47C USA S/N 74-22287
 FIBERGLASS ROTOR BLADES
 IN GROUND EFFECT
 10 FOOT TETHERED HOVER

- NOTES: 1. WHEEL HEIGHT MEASURED FROM BOTTOM OF RIGHT REAR WHEEL
 2. WIND LESS THAN 3 KNOTS
 3. AVERAGE OAT -9°C
 4. AVERAGE DENSITY ALTITUDE -100 FEET

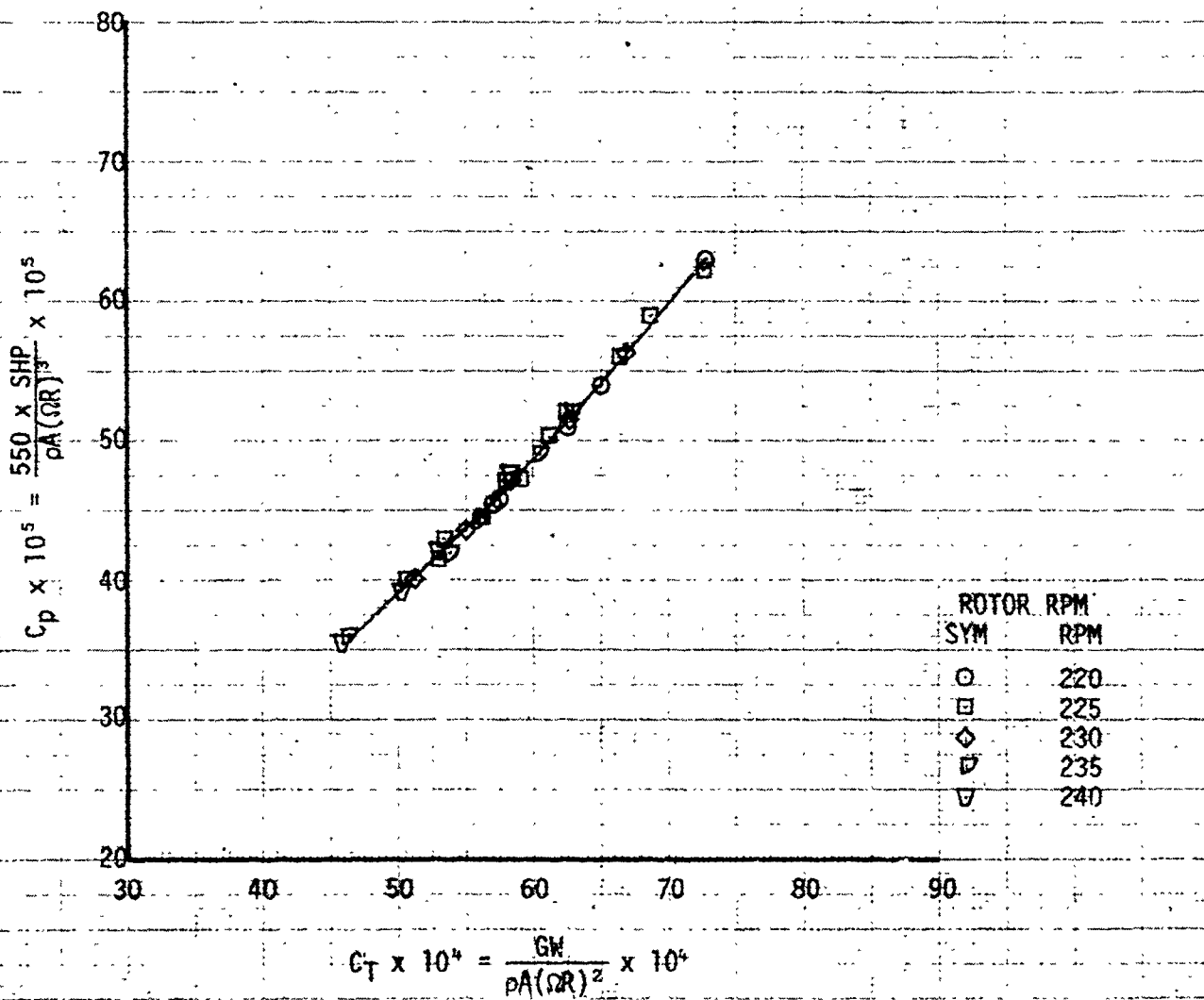


FIGURE 2
NON-DIMENSIONAL HOVER PERFORMANCE
 CH-47C USA S/N 74-22287
 FIBERGLASS ROTOR BLADES
 OUT-OF-GROUND EFFECT
 15L FOOT TETHERED HOVER

- NOTES: 1. WHEEL HEIGHT MEASURED FROM BOTTOM OF RIGHT-REAR WHEEL
 2. WIND LESS THAN 3 KNOTS
 3. AVERAGE OAT 9°
 4. AVERAGE DENSITY ALTITUDE -100 FEET

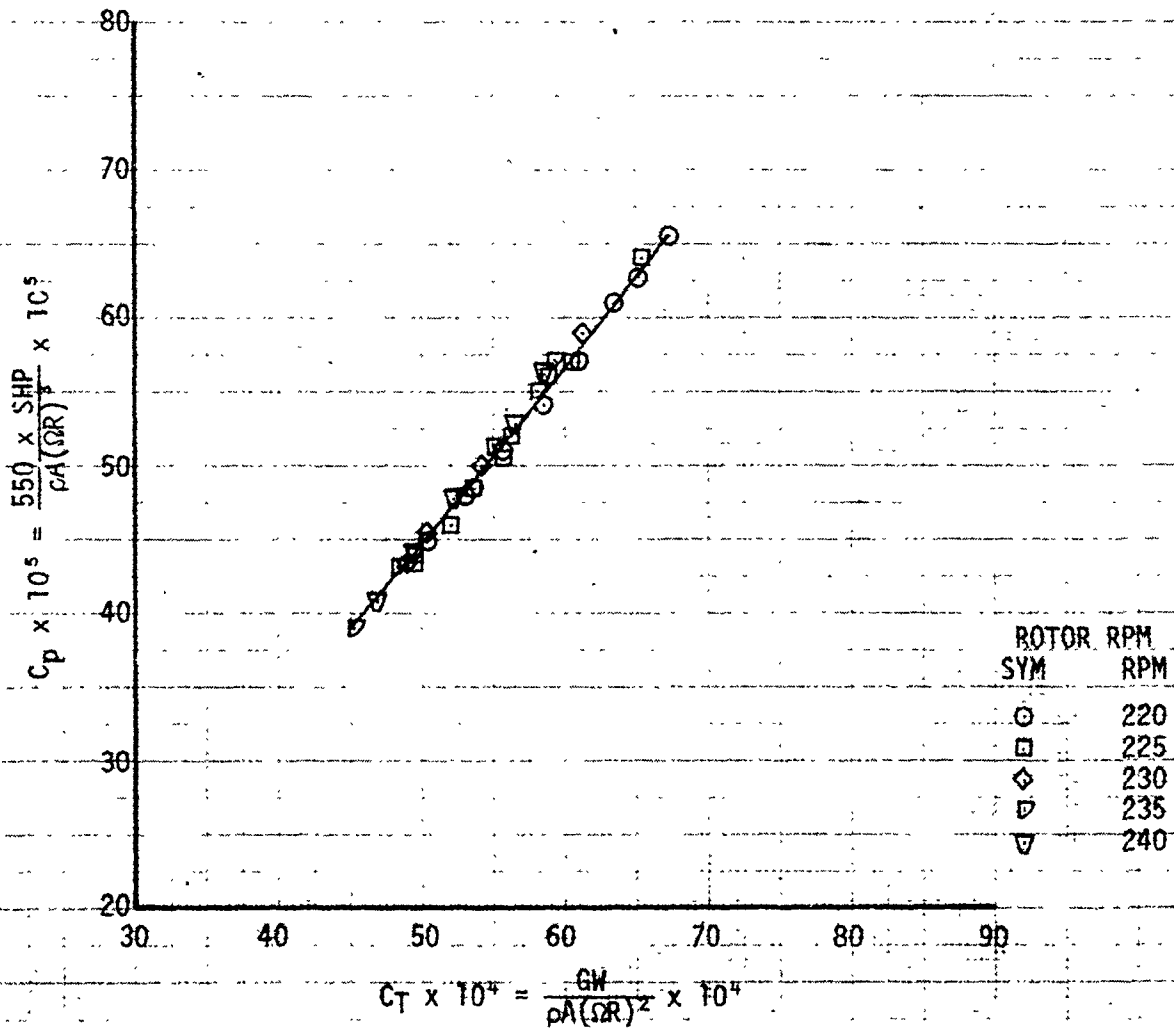


FIGURE 3
LEVEL FLIGHT PERFORMANCE

CH-47C USA S/N 74122287 FIBERGLASS ROTOR BLADES

SYM	N/G	Avg Ref	Avg Press	Avg OAT	Avg C.G.	Avg
		Gross Wt (LB)	Altitude (FT)	°C	Location (IN)	CT
○	225	33580	2100	12	330	49.76
□	225	40320	1000	11	332	59.50
○	225	43580	7900	8	331	64.32
△	225	48020	7300	8	330	71.82
◇	225	54620	6000	8	330	81.16

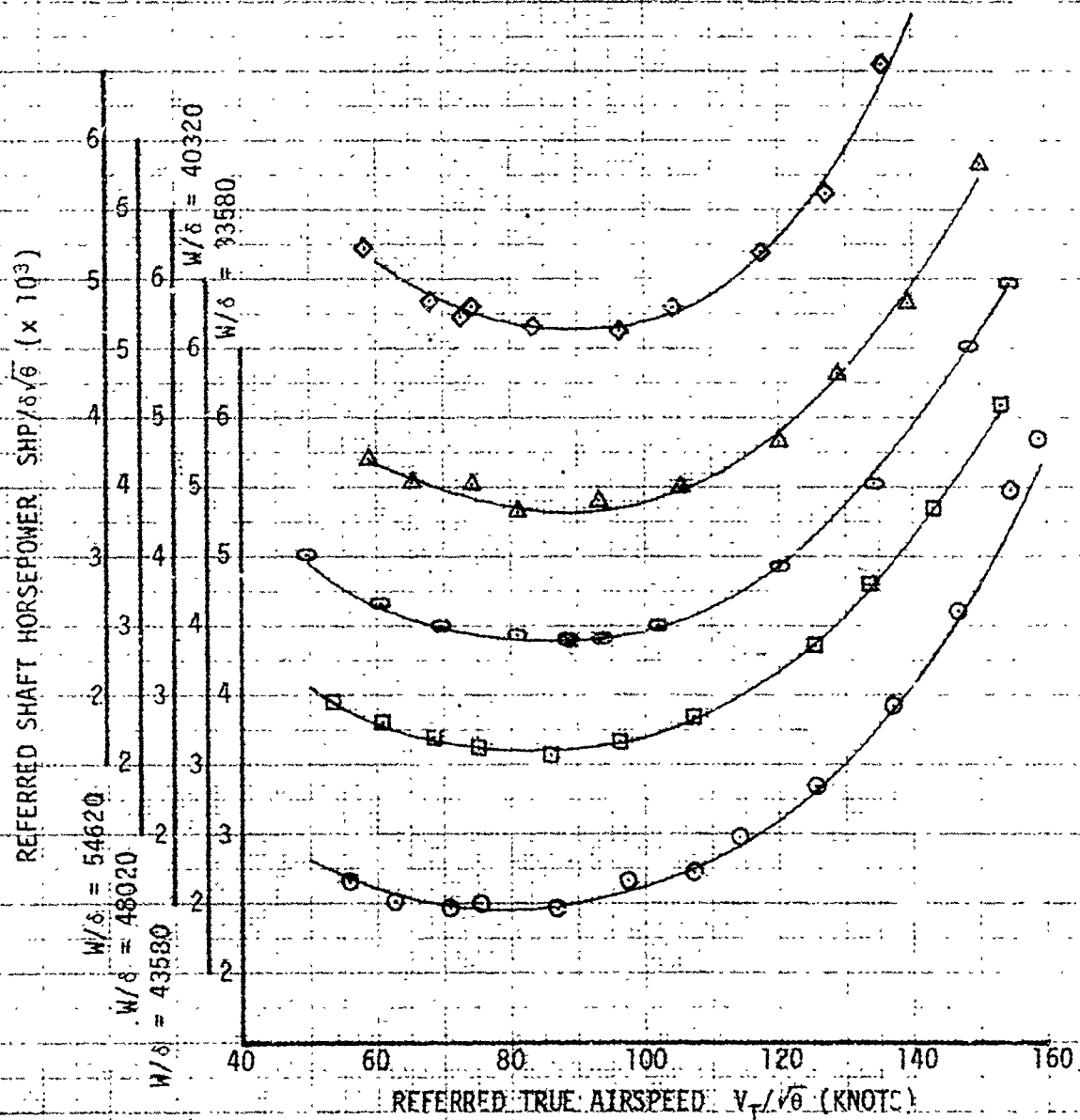


FIGURE 4
 CH-47C USA S/N 74-22287 FIBERGLASS ROTOR BLADES
 $N/\sqrt{\theta} = 225$ RPM

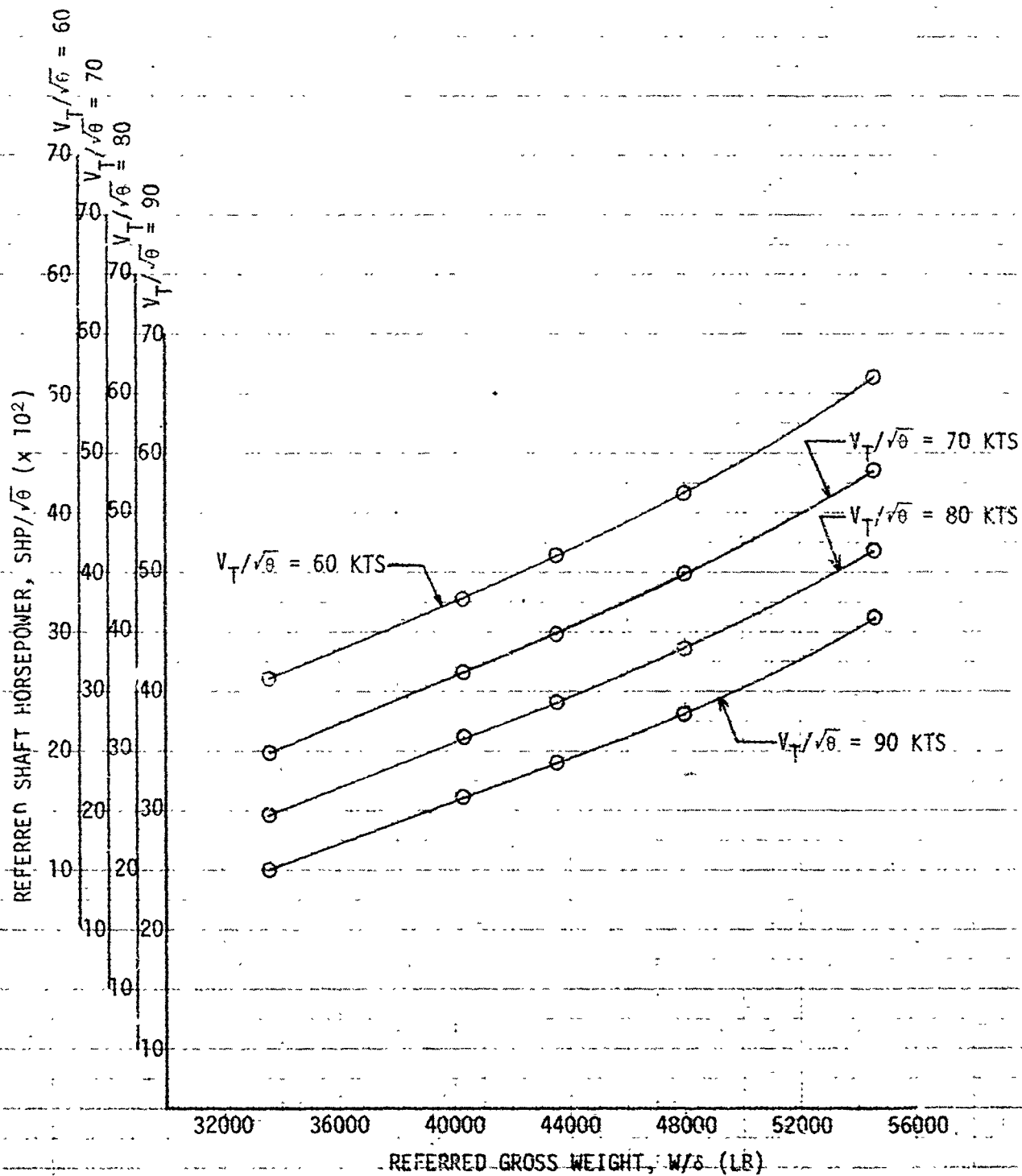


FIGURE 5
 LEVEL FLIGHT PERFORMANCE
 CH-47C USA S/N 74-222B7 FIBERGLASS ROTOR BLADES
 $N/\theta = 225$ RPM.

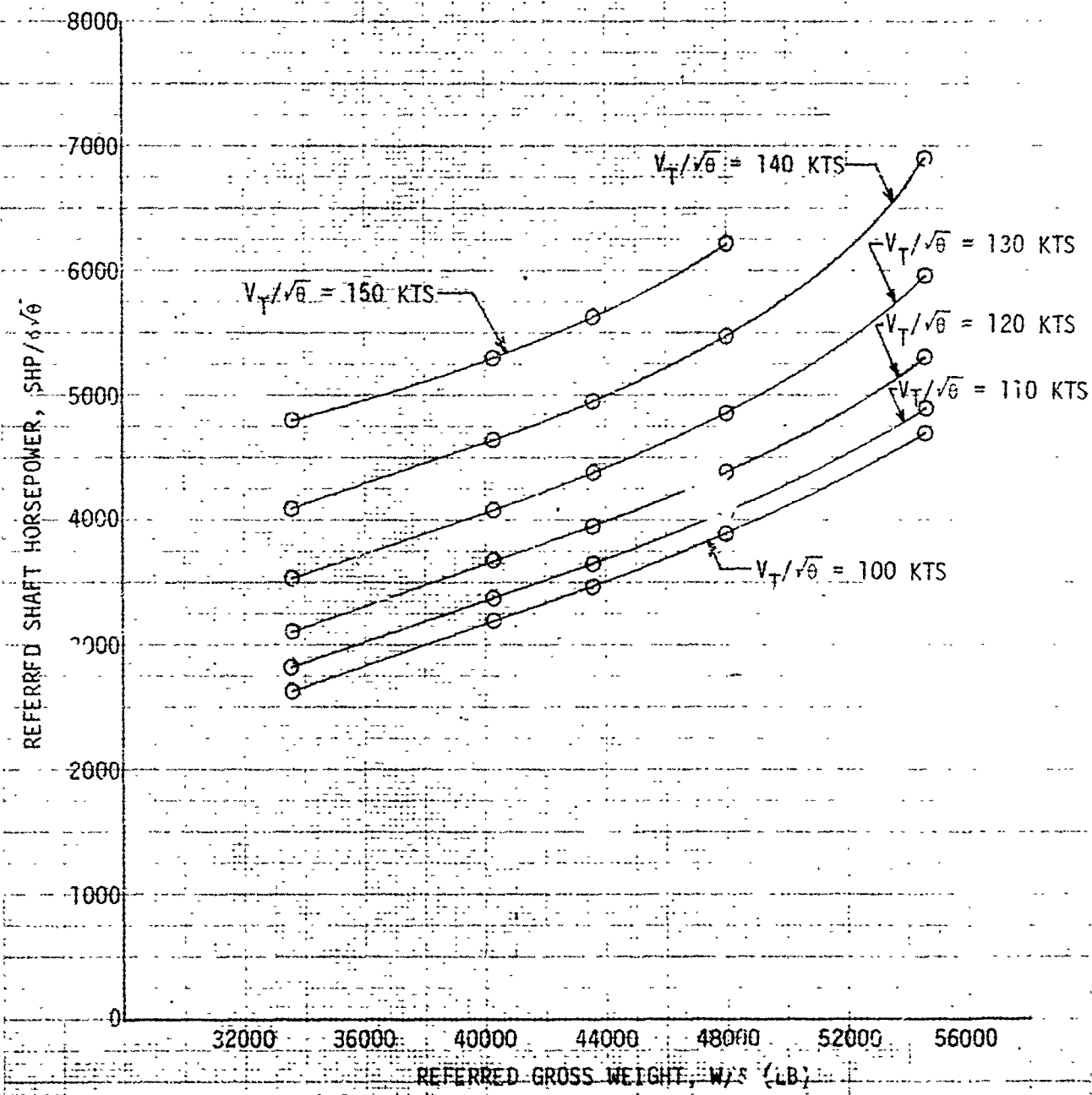
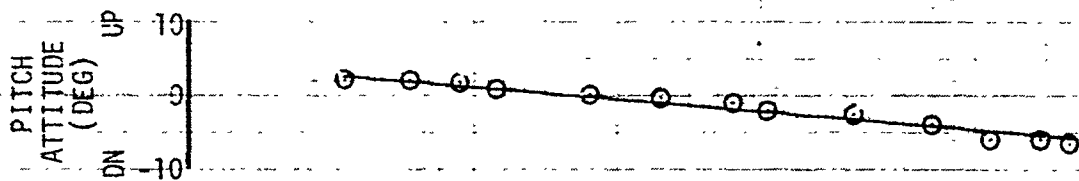
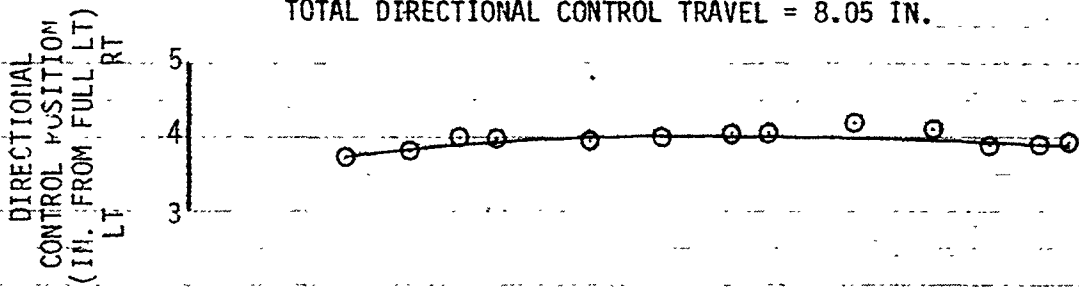


FIGURE 6
 CONTROL POSITIONS IN TRIMMED FORWARD FLIGHT
 CH-47C USA S/N 74-22287 FIBERGLASS ROTOR BLADES

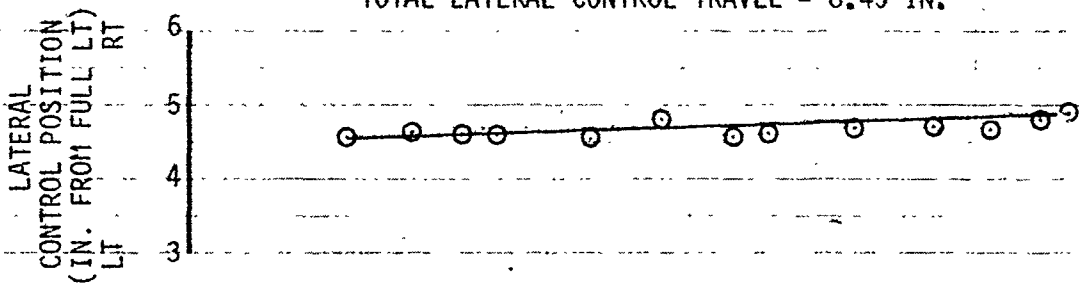
AVG GROSS WEIGHT (LB)	AVG CG LOCATION (IN. FS.)	AVG DENSITY ALTITUDE (FT)	AVG OAT (°C)	AVG ROTOR SPEED (RPM)	AVG C_T	PSAS MODE
31200	330	2100	12	224	.004976	AUTO



TOTAL DIRECTIONAL CONTROL TRAVEL = 8.05 IN.



TOTAL LATERAL CONTROL TRAVEL = 8.45 IN.



TOTAL LONGITUDINAL CONTROL TRAVEL = 13.90 IN.

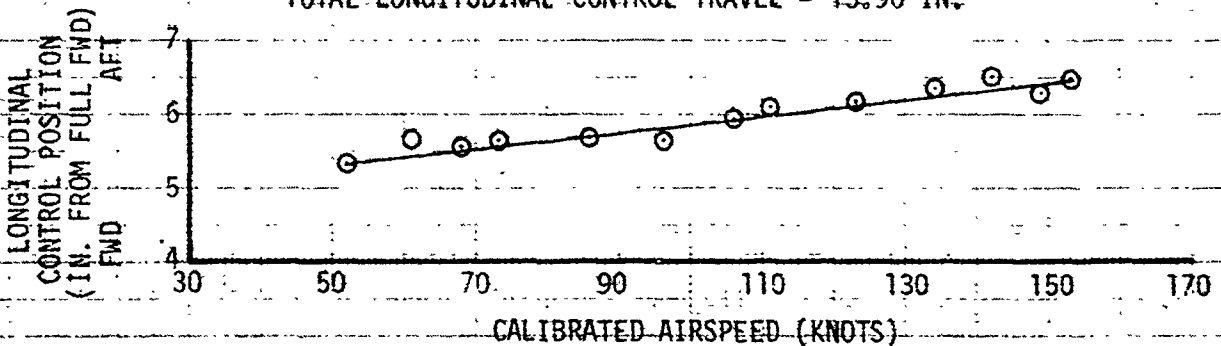
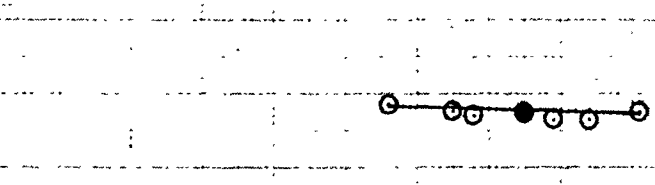


FIGURE 7
 STATIC LONGITUDINAL STABILITY
 CH-47C USA S/N 74-22287 FIBERGLASS ROTOR BLADES

FLIGHT CONDITION	AVG GROSS WEIGHT (LB)	AVG CG LOCATION (IN. FS.)	AVG DENSITY ALTITUDE (FT)	AVG OAT (°C)	AVG ROTOR SPEED (RPM)	TRIM A/S (KCAS)	PSAS MODE
LEVEL FLT	45000	335	4700	11	224	105	NORMAL

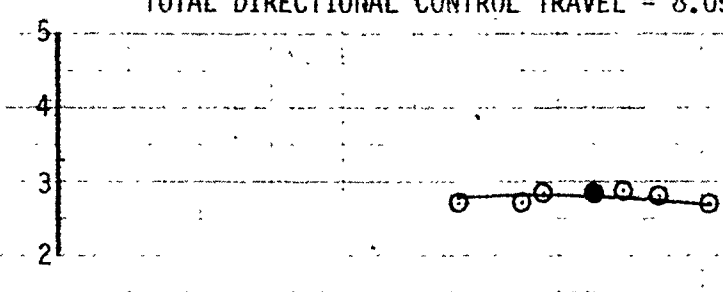
NOTE: SHADED POINTS DENOTES TRIM

PITCH ATTITUDE (DEG)
 UP
 DN



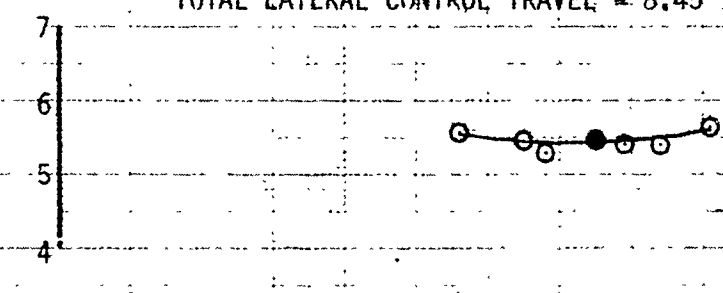
TOTAL DIRECTIONAL CONTROL TRAVEL = 8.05 IN.

DIRECTIONAL CONTROL POSITION (IN. FROM FULL LT) RT
 LT



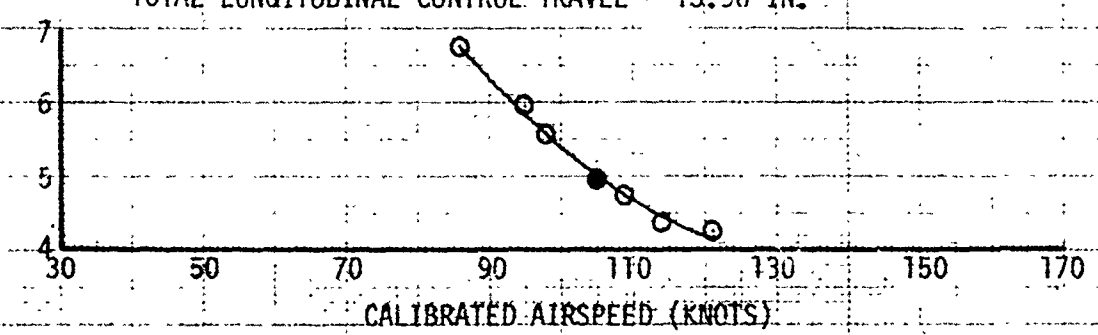
TOTAL LATERAL CONTROL TRAVEL = 8.45 IN.

LATERAL CONTROL POSITION (IN. FROM FULL LT) RT
 LT



TOTAL LONGITUDINAL CONTROL TRAVEL = 13.90 IN.

LONGITUDINAL CONTROL POSITION (IN. FROM FULL FWD) AFT
 FWD



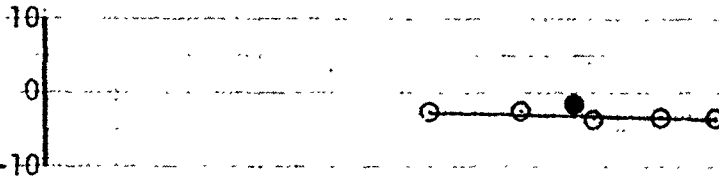
CALIBRATED AIRSPEED (KNOTS)

FIGURE 8
STATIC LONGITUDINAL STABILITY
CH-47C USA S/N 74-22287 FIBERGLASS ROTOR BLADES

FLIGHT CONDITION	AVG GROSS WEIGHT (LB)	AVG CG LOCATION (IN. FS.)	AVG DENSITY ALTITUDE (FT)	AVG OAT (°C)	AVG ROTOR SPEED (RPM)	TRIM A/S (KCAS)	PSAS MODE
LEVEL FLT	45000	335	4700	11	225	104	OFF

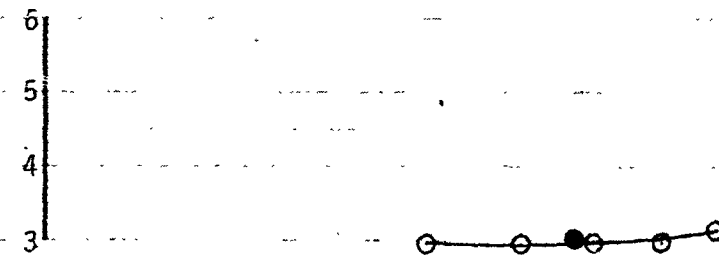
NOTE: SHADED POINTS DENOTES TRIM

PITCH ATTITUDE (DEG)
 UP
 DN



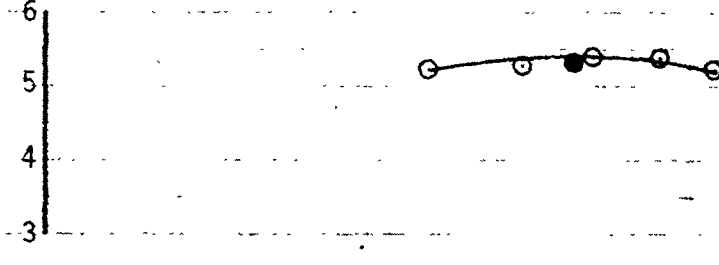
TOTAL DIRECTIONAL CONTROL TRAVEL = 8.05 IN.

DIRECTIONAL CONTROL POSITION (IN. FROM FULL LT) RT
 LT



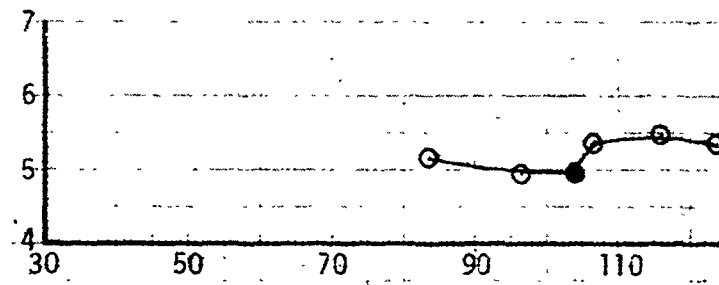
TOTAL LATERAL CONTROL TRAVEL = 8.45 IN.

LATERAL CONTROL POSITION (IN. FROM FULL LT) RT
 LT



TOTAL LONGITUDINAL CONTROL TRAVEL = 13.90 IN.

LONGITUDINAL CONTROL POSITION (IN. FROM FULL FWD) AFT
 FWD

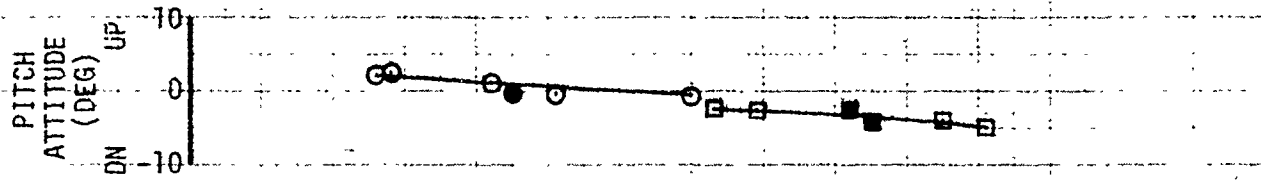


CALIBRATED AIRSPEED (KNOTS)

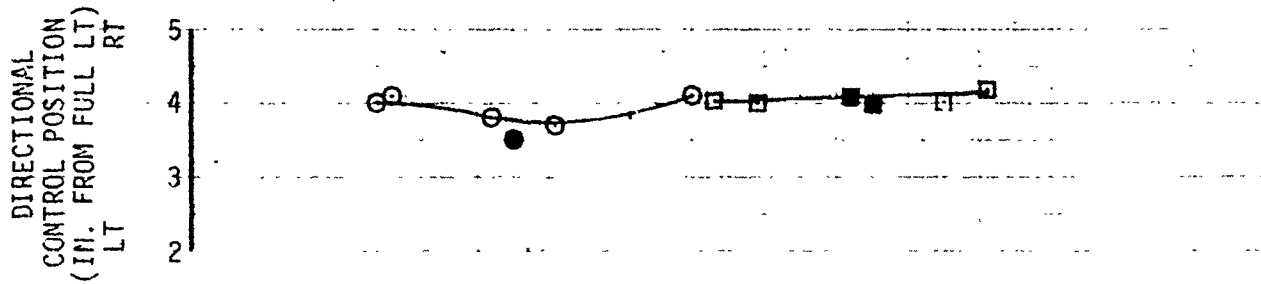
FIGURE 9
STATIC LONGITUDINAL STABILITY
CH-47C USA S/N 74-22287 FIBERGLASS ROTOR BLADES

SYM	FLIGHT CONDITION	AVG GROSS WEIGHT (LB)	AVG CG LOCATION (IN. FS.)	AVG DENSITY ALTITUDE (FT)	AVG OAT (°C)	AVG ROTOR SPEED (RPM)	INITIAL TRIM A/S (KCAS)	PSAS MODE
○	LEVEL FLT	34000	341.8	5060	6	225	75	OFF
□	LEVEL FLT	33200	342.3	4700	6	225	125	OFF

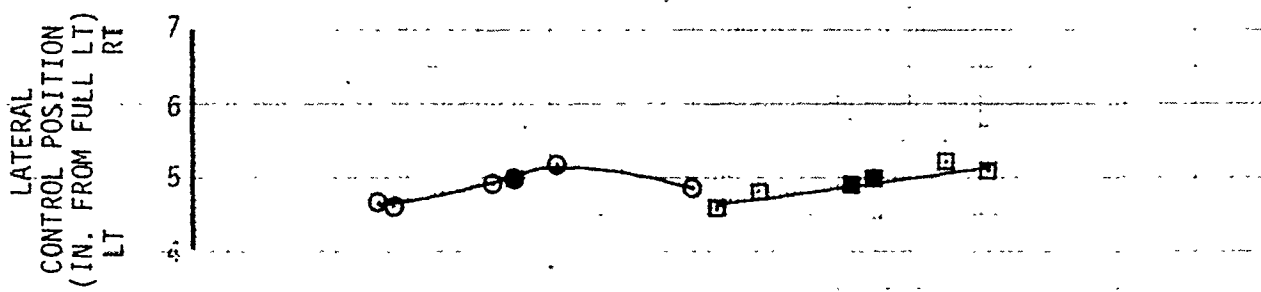
NOTE: SHADED POINTS DENOTES TRIM



TOTAL DIRECTIONAL CONTROL TRAVEL = 8.05 IN.



TOTAL LATERAL CONTROL TRAVEL = 8.45 IN.



TOTAL LONGITUDINAL CONTROL TRAVEL = 13.90 IN.

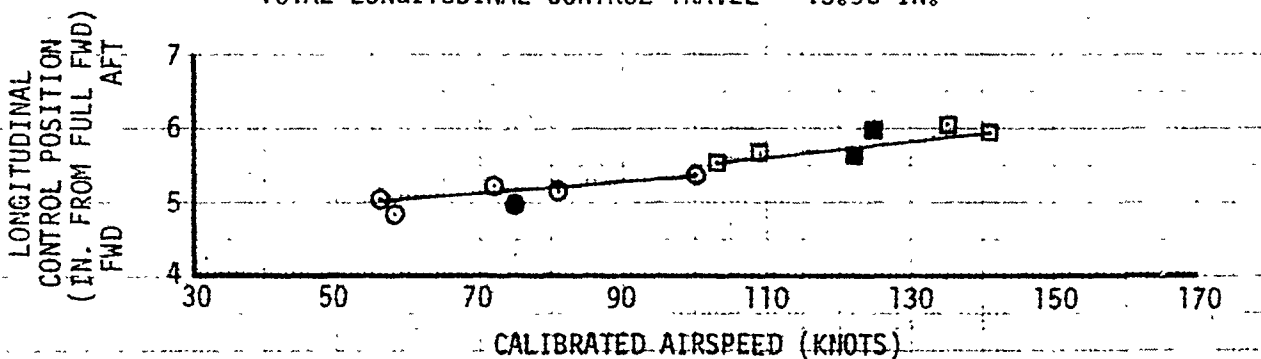
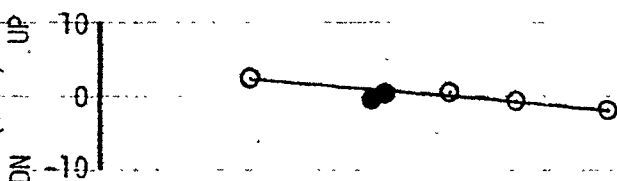


FIGURE 10
 STATIC LONGITUDINAL STABILITY
 CH-47C USA S/N 74-22287 FIBERGLASS ROTOR BLADES

FLIGHT CONDITION	AVG GROSS WEIGHT (LB)	AVG CG LOCATION (IN. FS.)	AVG DENSITY ALTITUDE (FT)	AVG OAT (°C)	AVG ROTOR SPEED (RPM)	INITIAL TRIM A/S (KCAS)	PSAS MODE
CLIMB	33000	341	6500	5	224	68	OFF

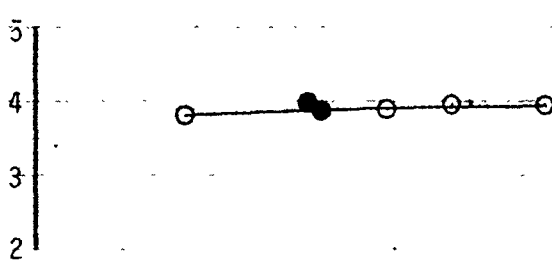
NOTE: SHADED POINTS DENOTES TRIM

PITCH ATTITUDE (DEG)
 UP
 DN



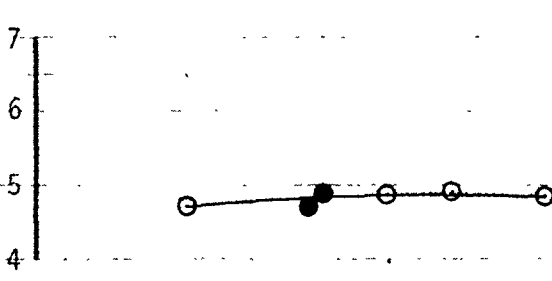
TOTAL DIRECTIONAL CONTROL TRAVEL = 8.05 IN.

DIRECTIONAL CONTROL POSITION (IN. FROM FULL LT) RT
 LT



TOTAL LATERAL CONTROL TRAVEL = 8.45 IN.

LATERAL CONTROL POSITION (IN. FROM FULL LT) RT
 LT



TOTAL LONGITUDINAL CONTROL TRAVEL = 13.90 IN.

LONGITUDINAL CONTROL POSITION (IN. FROM FULL FWD) AFT
 FWD

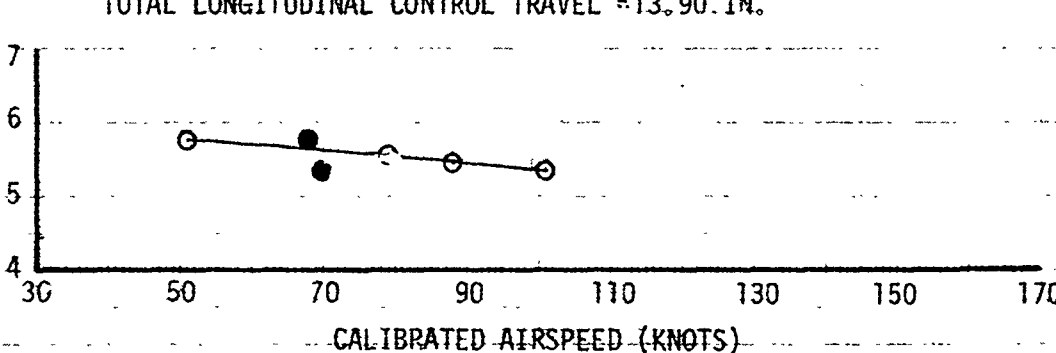
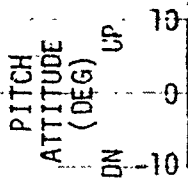


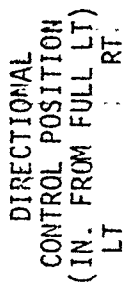
FIGURE 11
STATIC LONGITUDINAL STABILITY
CH-47C USA S/N 74-22287 FIBERGLASS ROTOR BLADES

FLIGHT CONDITION	AVG GROSS WEIGHT (LB)	AVG CG LOCATION (IN. FS.)	AVG DENSITY ALTITUDE (FT)	AVG OAT (°C)	AVG ROTOR SPEED (RPM)	TRIM A/S (KCAS)	PSAS MODE
AUTO	32809	341	5500	5	225	67	OFF

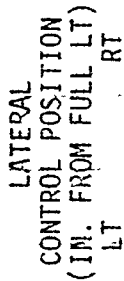
NOTE: SHADED POINTS DENOTES TRIM



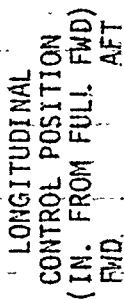
TOTAL DIRECTIONAL CONTROL TRAVEL = 8.05 IN.



TOTAL LATERAL CONTROL TRAVEL = 8.45 IN.



TOTAL LONGITUDINAL CONTROL TRAVEL = 13.90 IN.



CALIBRATED AIRSPEED (KNOTS)

FIGURE 12
STATIC LATERAL DIRECTIONAL STABILITY
CH-47C USA S/N 74-22287 FIBERGLASS ROTOR BLADES

FLIGHT CONDITION	AVG GROSS WEIGHT (LB)	AVG CG LOCATION (IN. FS.)	AVG DENSITY ALTITUDE (FT)	AVG OAT (°C)	AVG ROTOR SPEED (RPM)	TRIM A/S (KCAS)	PSAS MODE
LEVEL FLT	31900	342	5600	10	225	120	OFF

NOTE: SHADED POINTS DENOTES TRIM

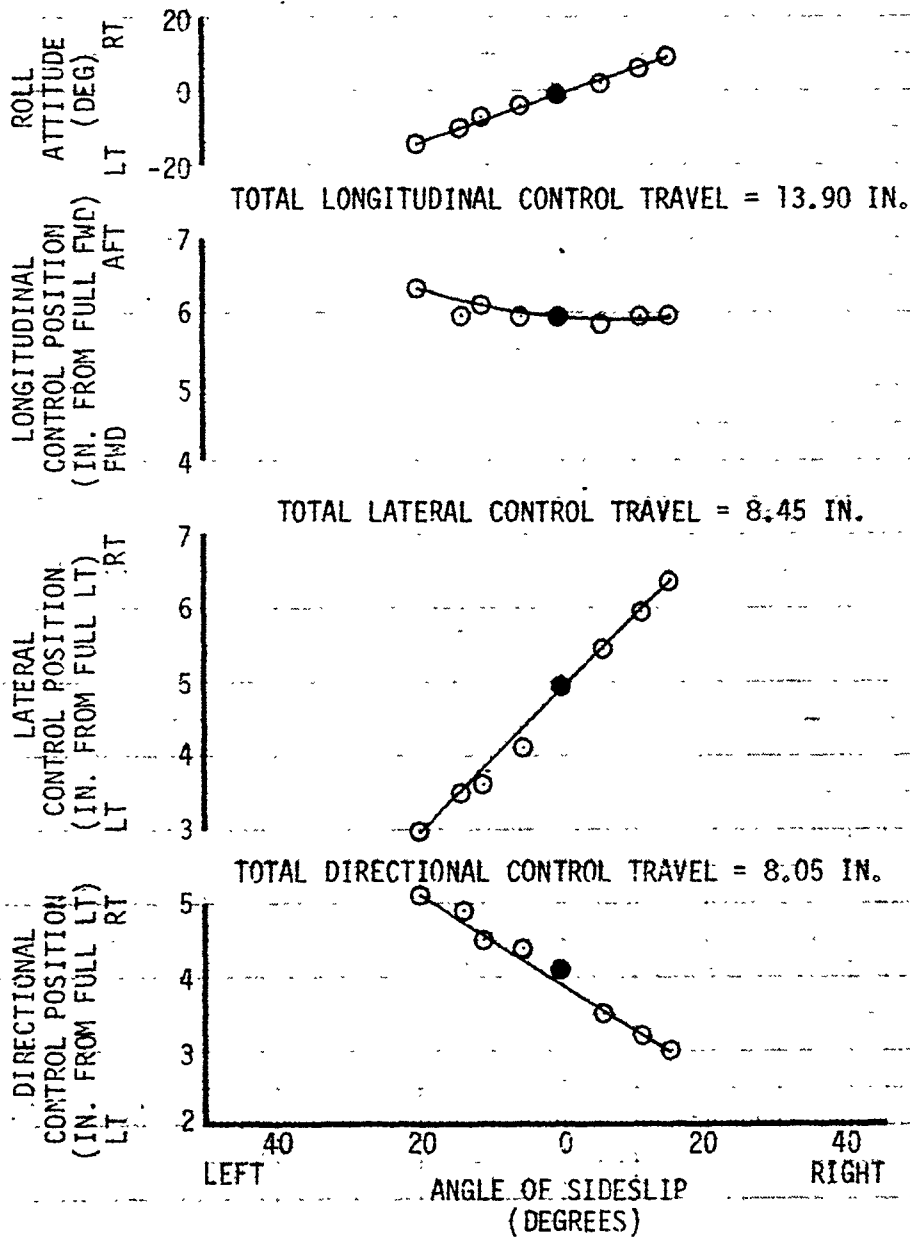


FIGURE 13
 STATIC LATERAL DIRECTIONAL STABILITY
 CH-47C USA S/N 74-22287 FIBERGLASS ROTOR BLADES

FLIGHT CONDITION	AVG GROSS WEIGHT (LB)	AVG CG. LOCATION (IN. FS.)	AVG DENSITY ALTITUDE (FT)	AVG OAT (°C)	AVG ROTOR SPEED (RPM)	TRIM A/S (KCAS)	PSAS MODE
LEVEL FLT	32400	342	5500	10	226	64	OFF

NOTE: SHADED POINTS DENOTES TRIM

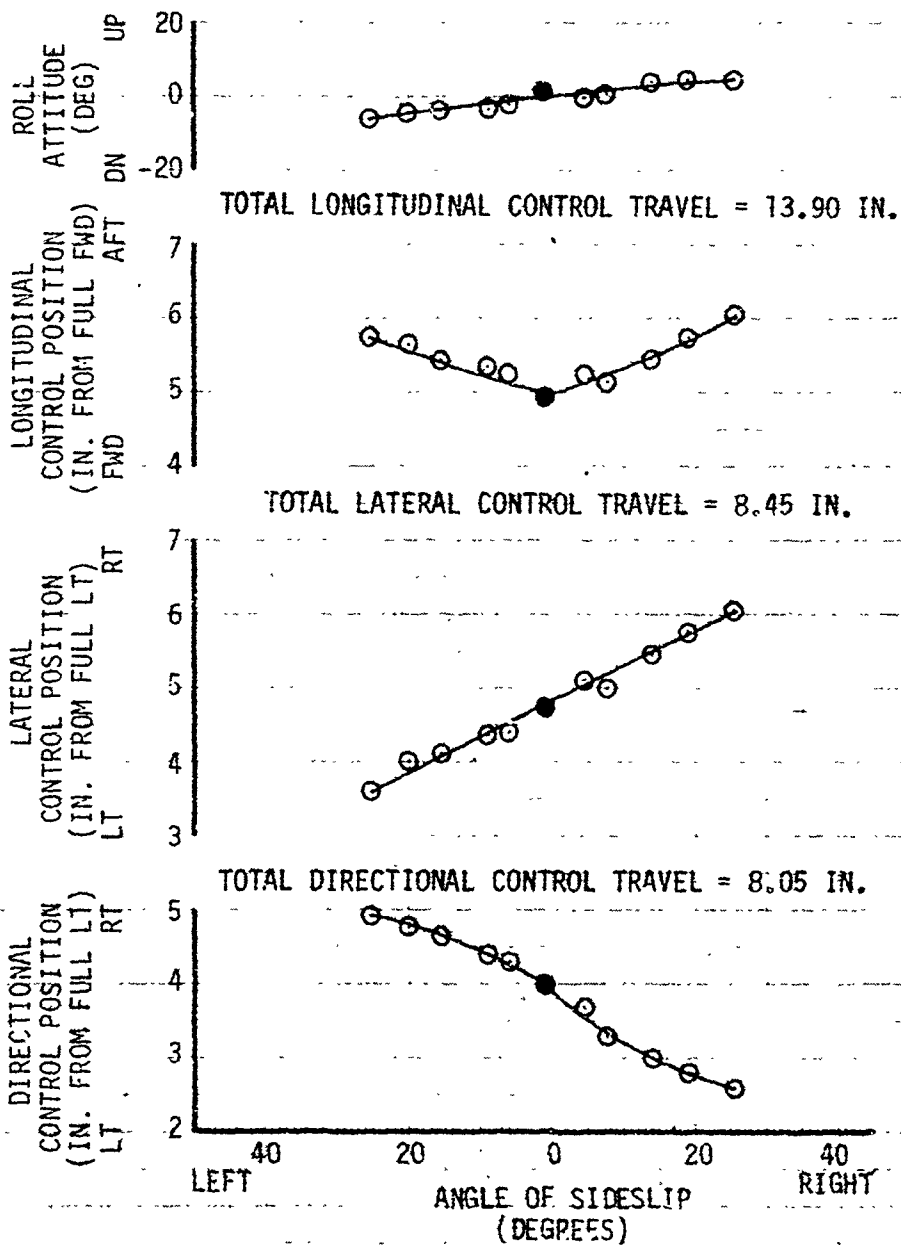


FIGURE 14
 MANEUVERING STABILITY
 CH-47C USA S/N 74-22287 FIBERGLASS ROTOR BLADES

AVG GROSS WEIGHT (LB)	AVG CG LOCATION (IN. FS.)	AVG DENSITY ALTITUDE (FT)	AVG OAT (°C)	AVG ROTOR SPEED (RPM)	TRIM A/S (KCAS)	PSAS MODE
31500	343	5480	10	226	130	OFF

○ DENOTES RIGHT TURNS
 □ DENOTES LEFT TURNS

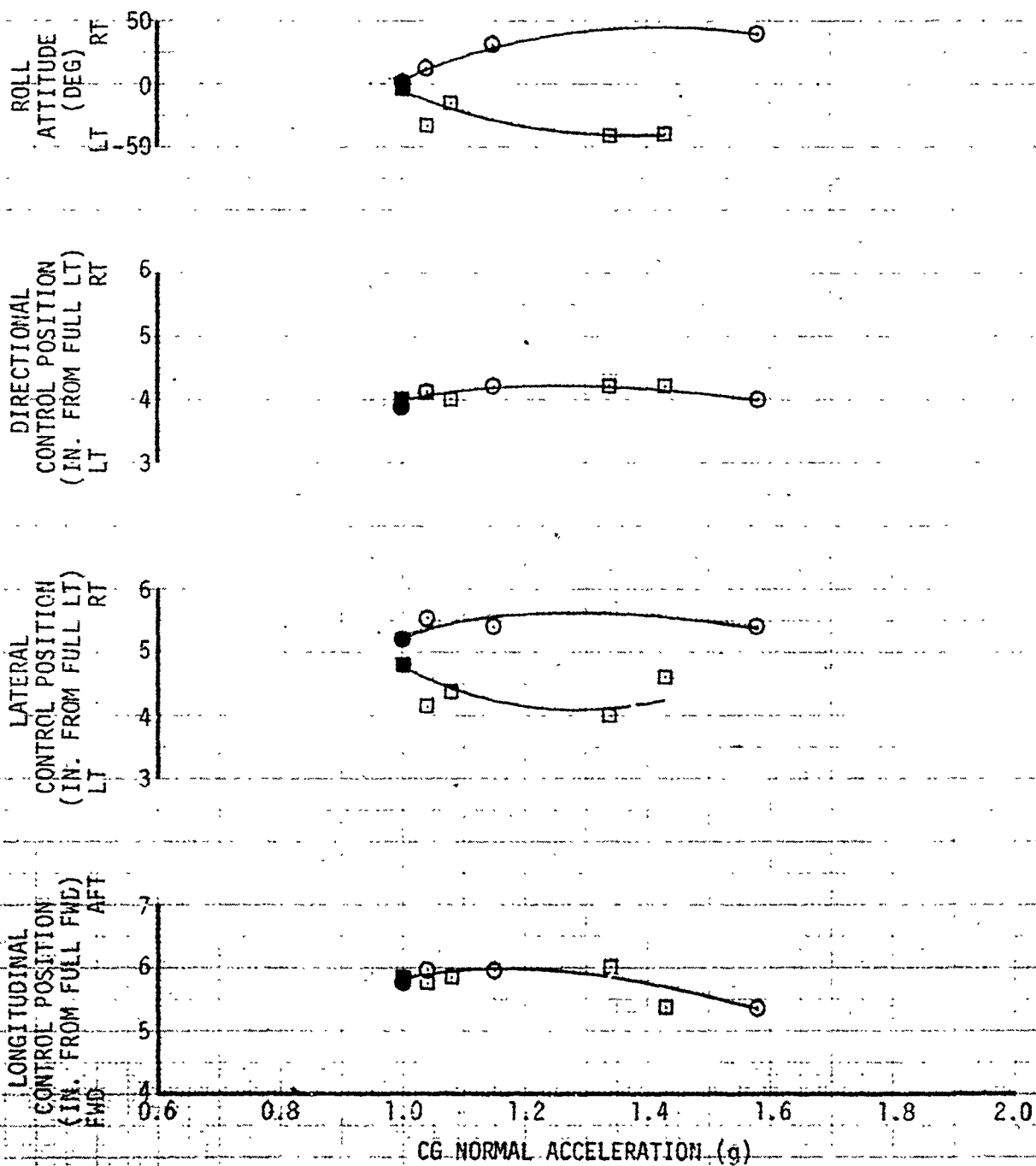


FIGURE 15
MANEUVERING STABILITY
CH-47C USA S/N 74-22287 FIBERGLASS ROTOR BLADES

AVG GROSS WEIGHT (LB)	AVG CG LOCATION (IN. FS.)	AVG DENSITY ALTITUDE (FT)	AVG OAT (°C)	AVG ROTOR SPEED (RPM)	TRIM A/S (KCAS)	PSAS MODE
31200	343	5660	10	225	67	OFF

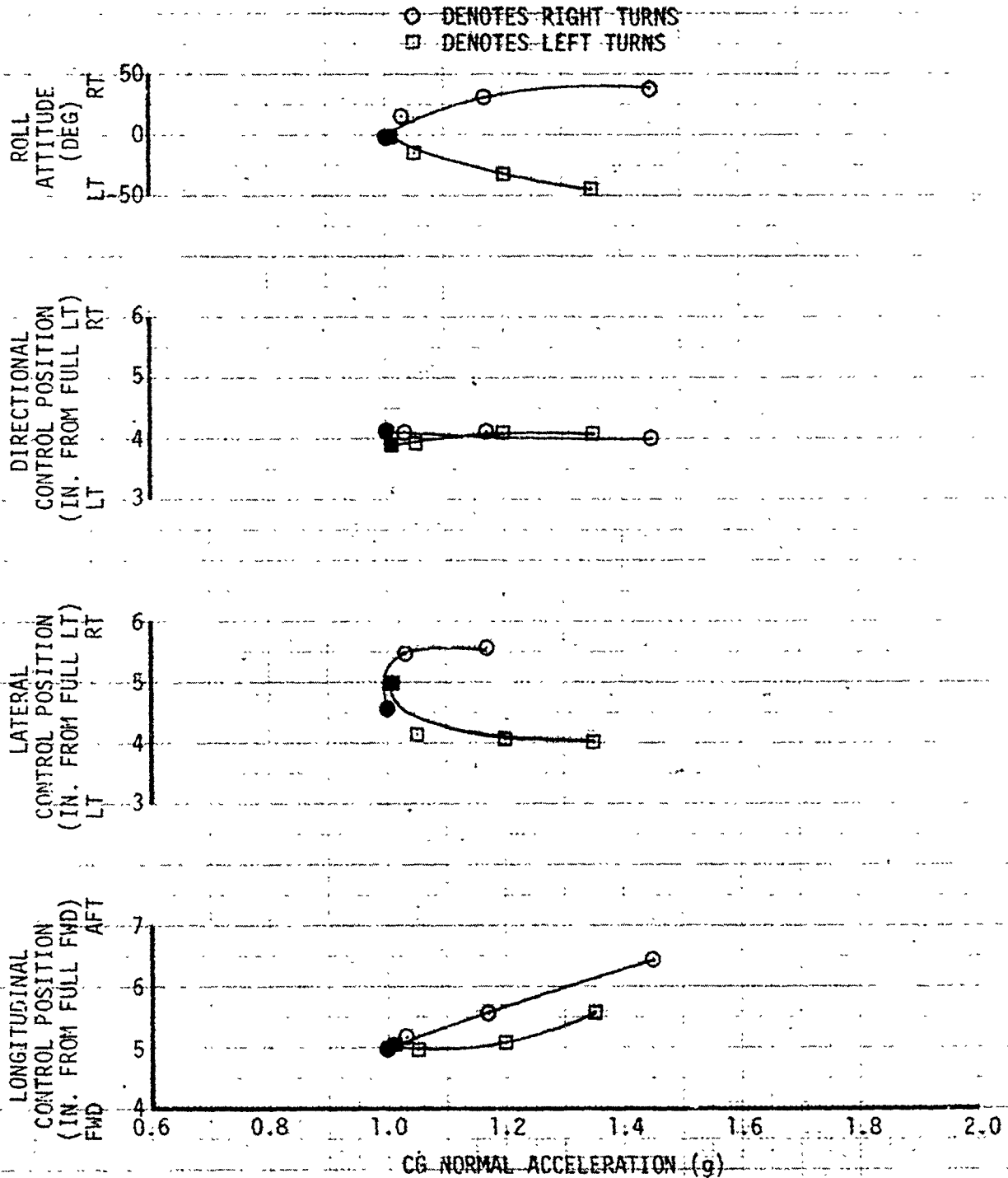


FIGURE 16
 LONGITUDINAL CONTROLLABILITY
 CH-47C USA S/N 74-22287 FIBERGLASS ROTOR BLADES
 HOVER

AVG GROSS WEIGHT (LB)	AVG DENSITY ALTITUDE (FT)	AVG OAT (°C)	AVG CG LOCATION (IN)	AVG ROTOR SPEED (RPM)	PSAS MODE
47200	300	8	334.3	224	NORM

30 FOOT REAR WHEEL HEIGHT

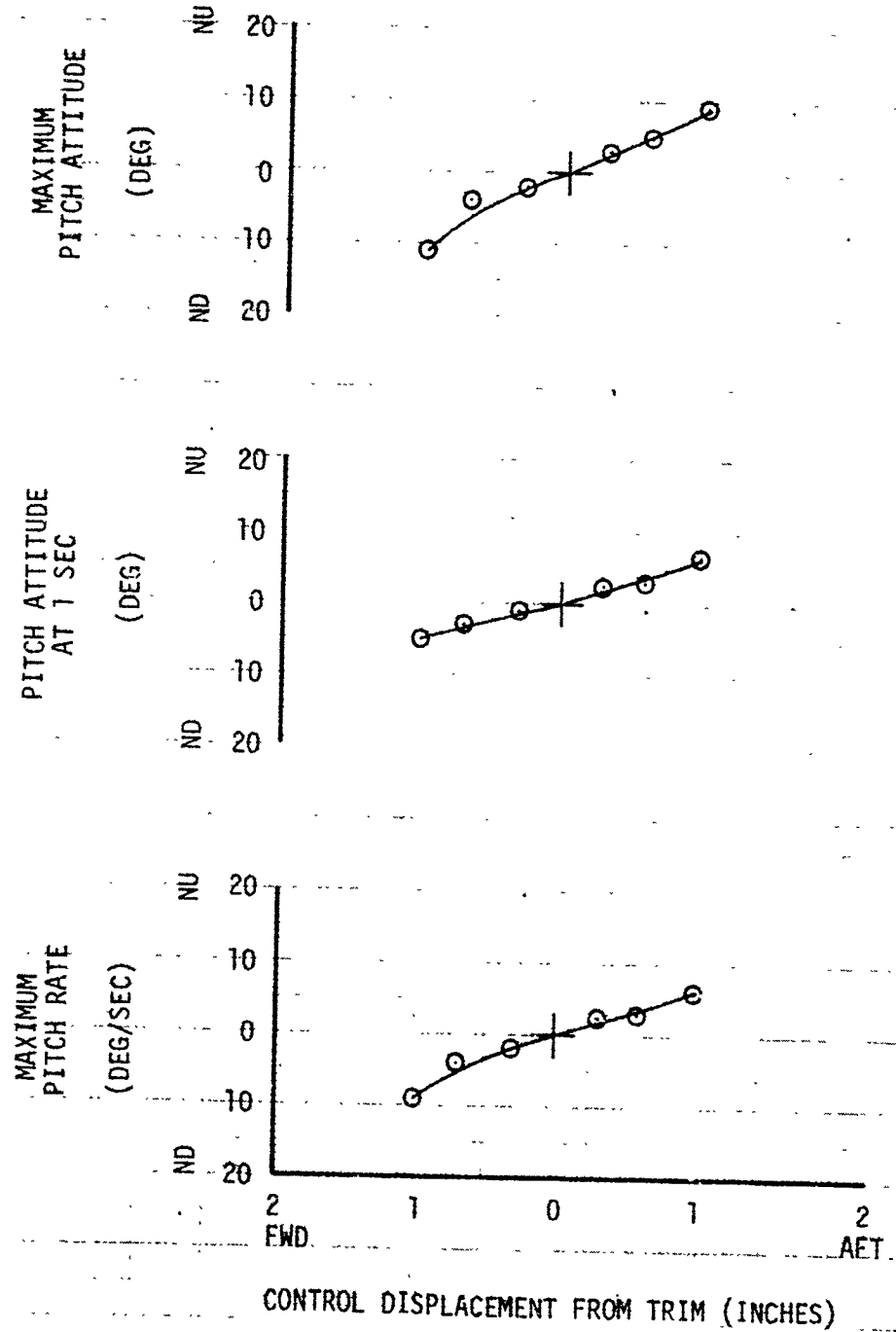


FIGURE 17
LATERAL CONTROLLABILITY
CH-47C USA S/N 74-22287 FIBERGLASS ROTOR BLADES
HOVER

AVG GROSS WEIGHT (LB)	AVG DENSITY ALTITUDE (FT)	AVG OAT (°C)	AVG CG LOCATION (IN)	AVG ROTOR SPEED (RPM)	PSAS MODE
47000	300	8	334.4	224	NORM

30 FOOT REAR WHEEL HEIGHT

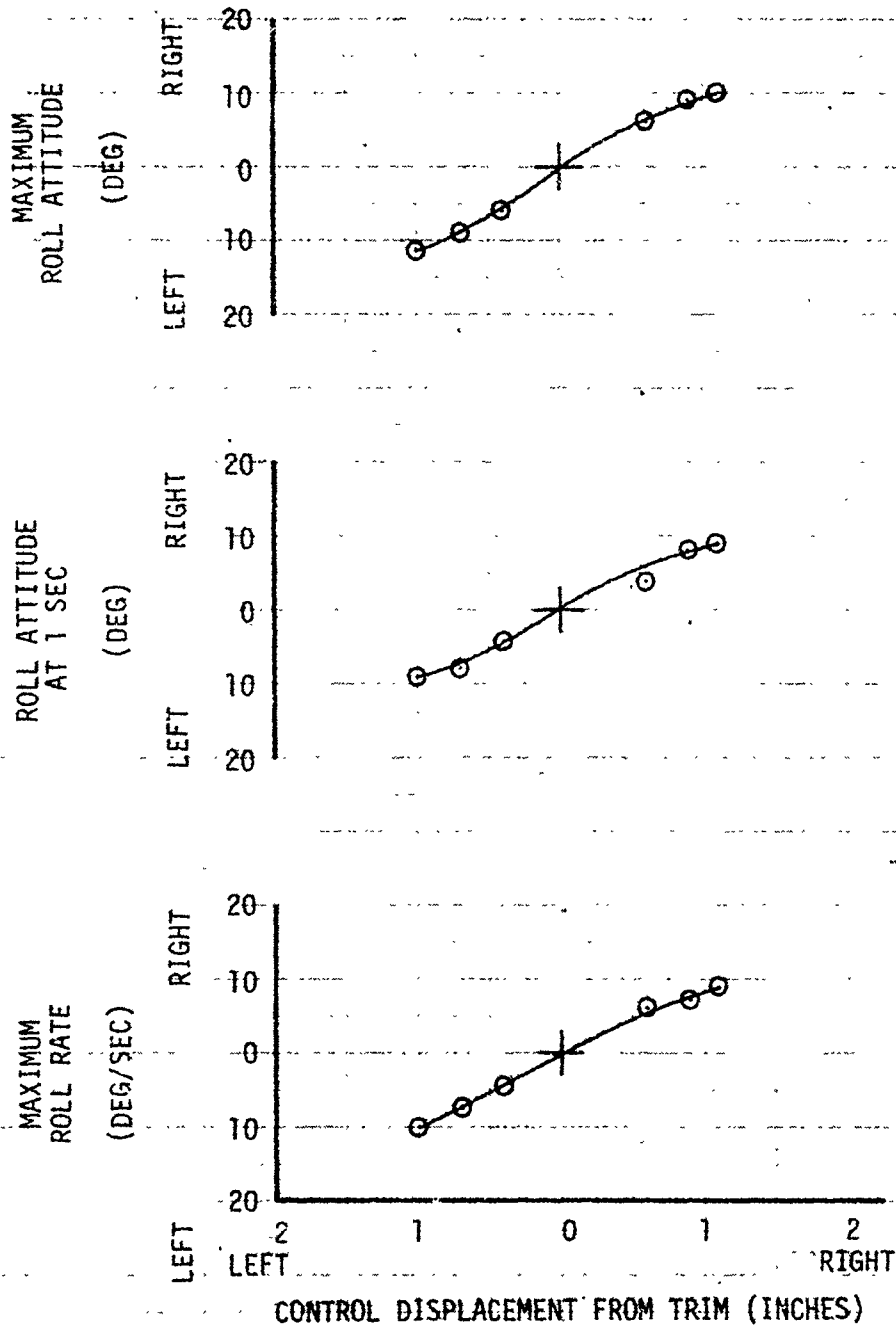
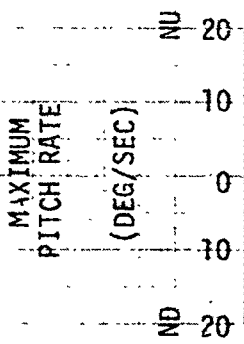
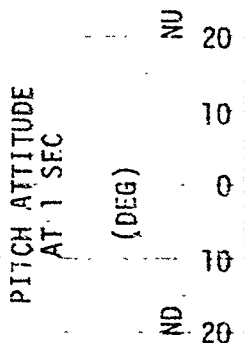
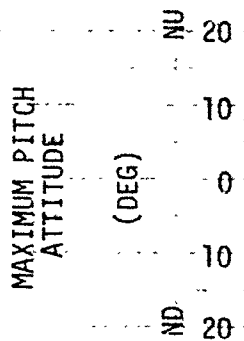


FIGURE 18
LONGITUDINAL CONTROLLABILITY
 CH-47C USA S/N 74-22287 FIBERGLASS ROTOR BLADES
 LEVEL FLIGHT

AVG GROSS WEIGHT (LB)	AVG DENSITY ALTITUDE (FT)	AVG OAT (°C)	AVG CG LOCATION (IN)	AVG ROTOR SPEED (RPM)	TRIM AIRSPEED (KCAS)	PSAS MODE
46000	5260	6	334.9	224	101	NORM



CONTROL DISPLACEMENT FROM TRIM (INCHES)

FIGURE 19
 LATERAL CONTROLLABILITY
 CH-47C USA S/N 74-22287 FIBERGLASS ROTOR BLADES
 LEVEL FLIGHT

AVG GROSS WEIGHT (LB)	AVG DENSITY ALTITUDE (FT)	AVG OAT (°C)	AVG CG LOCATION (IN)	AVG ROTOR SPEED (RPM)	TRIM AIRSPEED (KCAS)	PSAS MODE
45650	5200	7	335.5	224	102	NORM

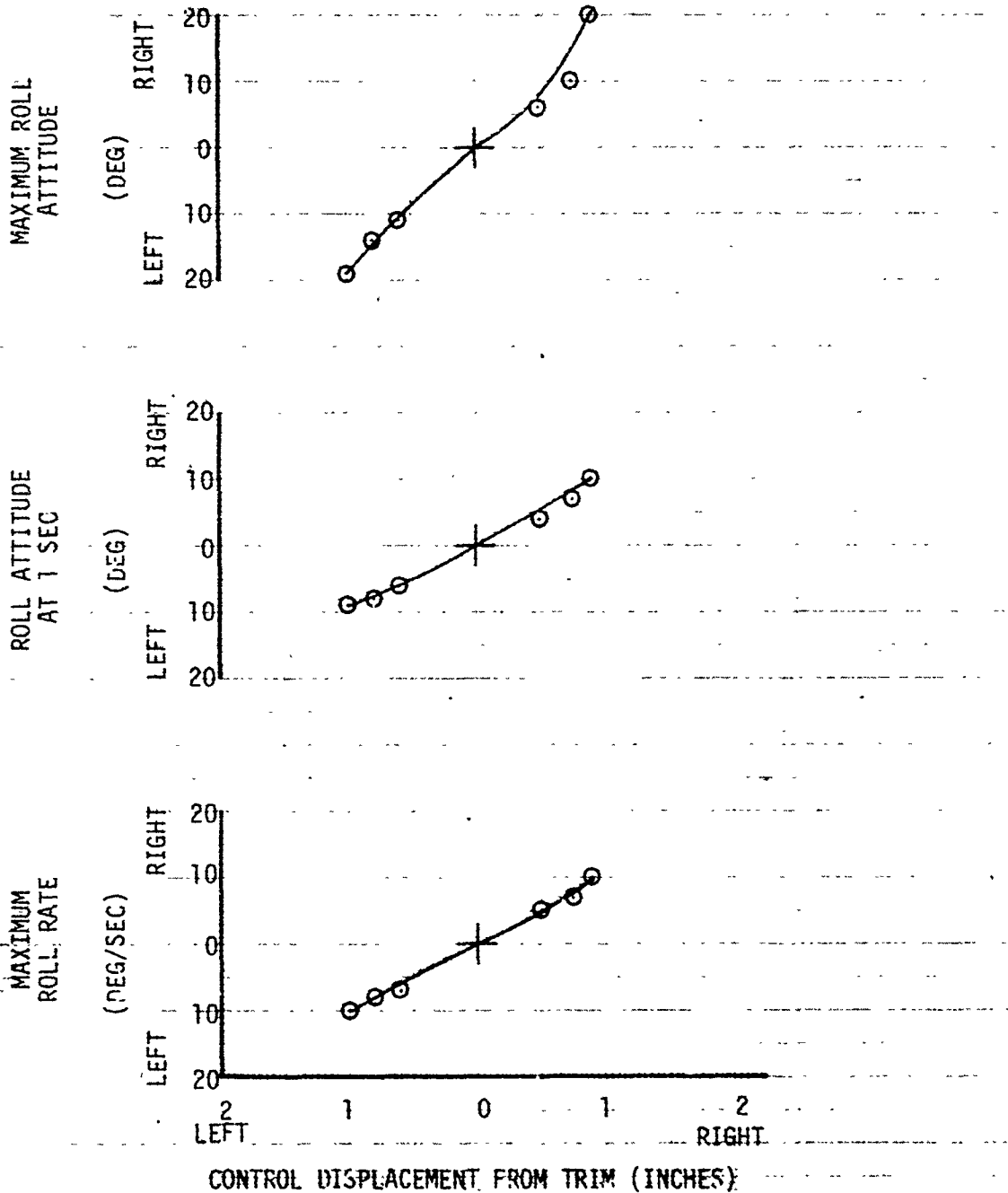
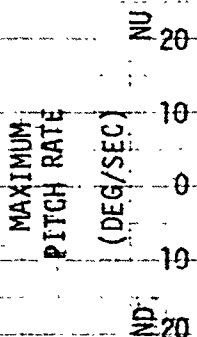
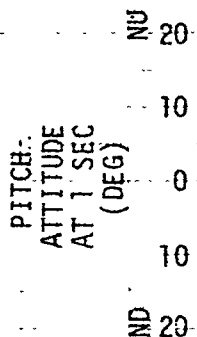
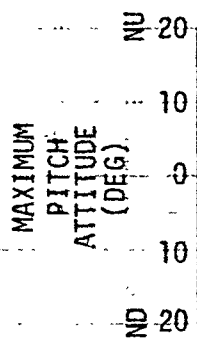


FIGURE 20
 LONGITUDINAL CONTROLLEADABILITY
 CH-47C USA S/N 74-22287 FIBERGLASS ROTOR BLADES
 LEVEL FLIGHT

AVG GROSS WEIGHT (LB)	AVG DENSITY ALTITUDE (FT)	AVG OAT (°C)	AVG CG LOCATION (IN)	AVG ROTOR SPEED (RPM)	TRIM AIRSPEED (KCAS)	PSAS MODE
46500	5000	6	334.6	224	66	NORM



CONTROL DISPLACEMENT FROM TRIM (INCHES)

FIGURE 21
LATERAL CONTROLLABILITY
 CH-47C USA S/N 74-22287 FIBERGLASS ROTOR BLADES
 LEVEL FLIGHT

AVG GROSS WEIGHT (LB)	AVG DENSITY ALTITUDE (FT)	AVG OAT (°C)	AVG CG LOCATION (IN)	AVG ROTOR SPEED (RPM)	TRIM AIRSPEED (KCAS)	PSAS MODE
46300	5060	10	334.8	224	67	NORM

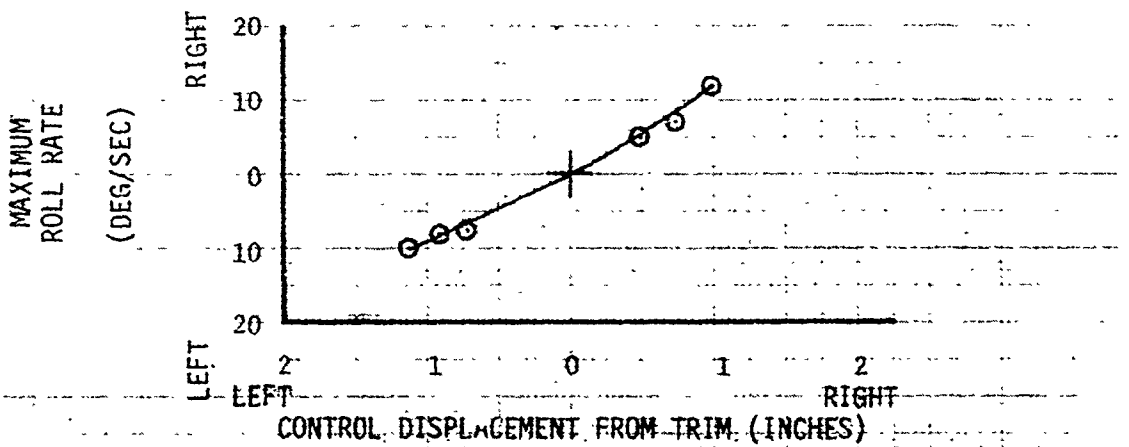
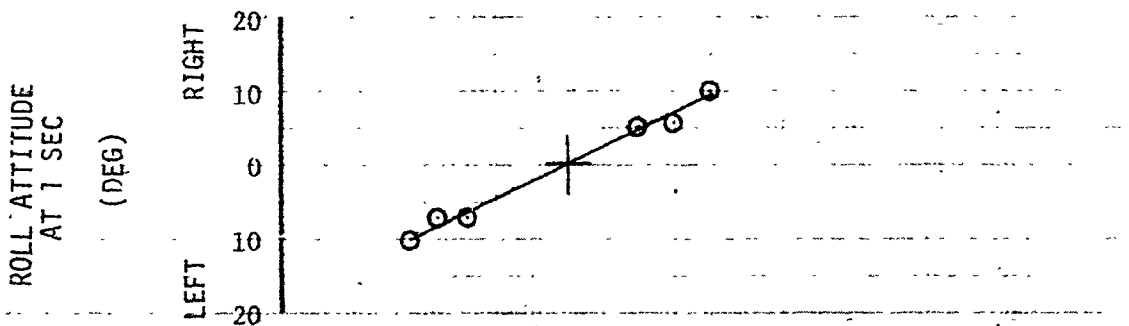
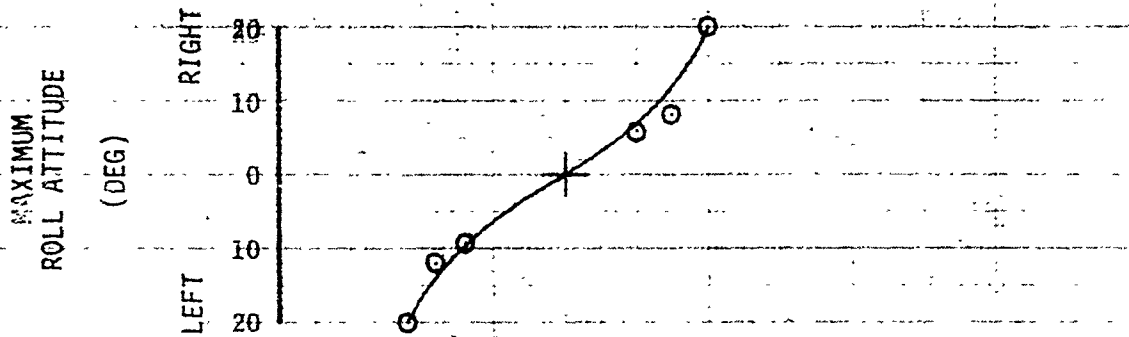


FIGURE 22

VIBRATION CHARACTERISTICS

CH-47C USA S/N 74-22287 FIBERGLASS ROTOR BLADES

AVG GROSS WEIGHT (LB)	AVG CG LOCATION (IN. F.S.S.)	AVG DENSITY ALTITUDE (FT)	AVG OAT (°C)	AVG ROTOR SPEED (RPM)
33000	330	3000	10	225

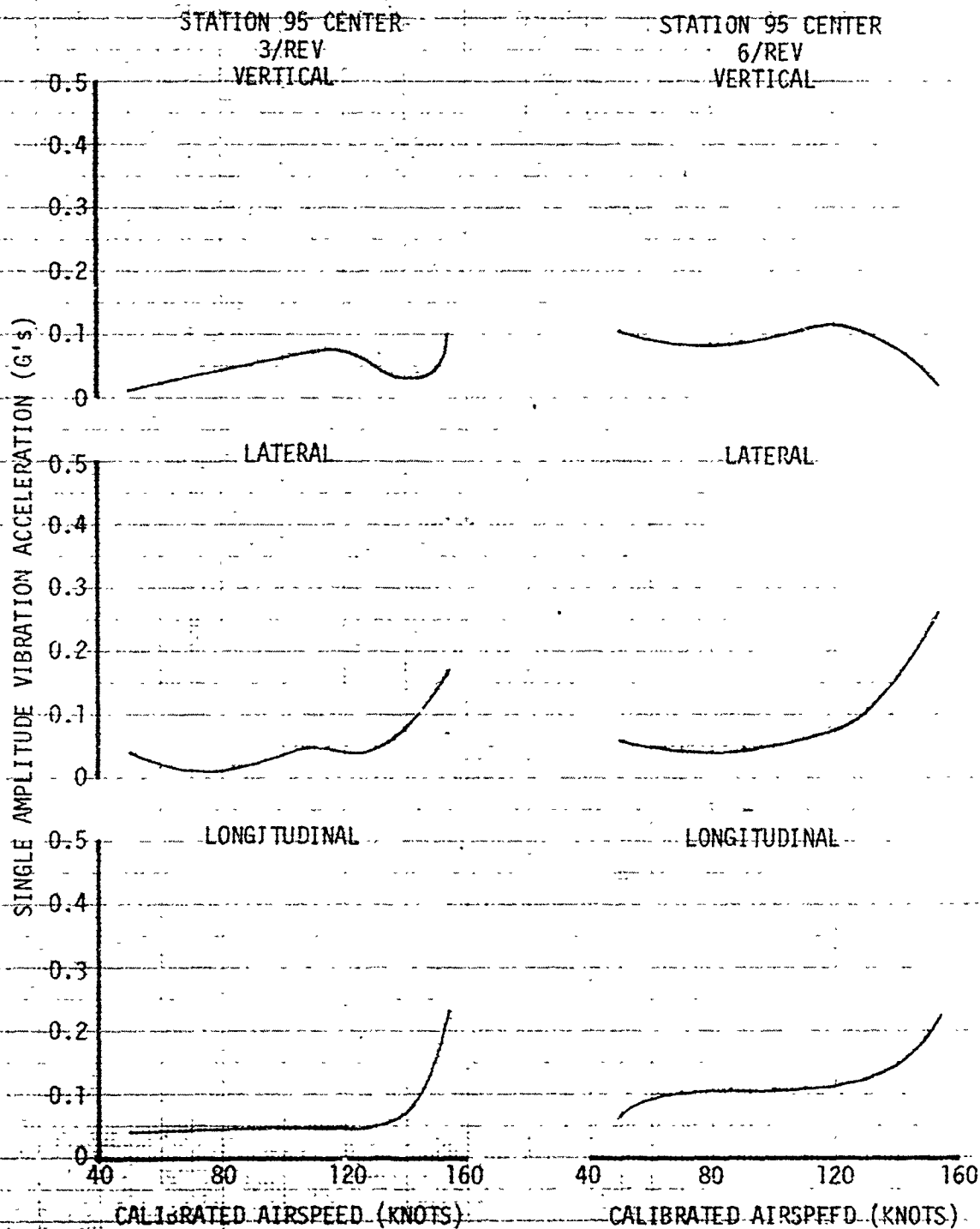


FIGURE 23

VIBRATION CHARACTERISTICS

CH-47C USA S/N 74-22287 FIBERGLASS ROTOR BLADES

AVG GROSS WEIGHT (LB)	AVG CG LOCATION (IN. F.S.)	AVG DENSITY ALTITUDE (FT)	AVG OAT (°C)	AVG ROTOR SPEED (RPM)
33000	330	3000	10	225

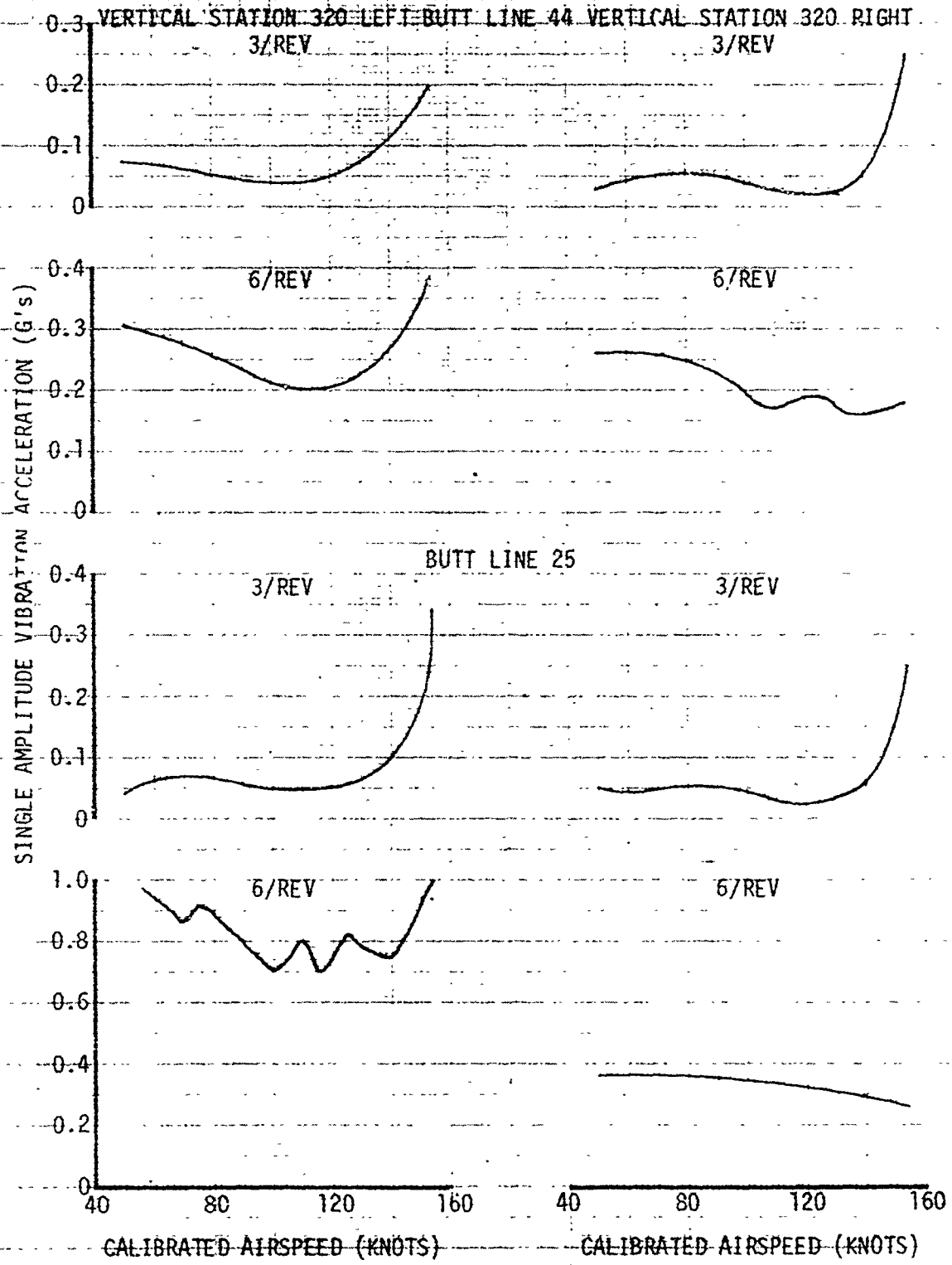


FIGURE 24

VIBRATION CHARACTERISTICS

CH-47C USA S/N 74-22287 FIBERGLASS ROTOR BLADES

AVG GROSS WEIGHT (LB)	AVG CG LOCATION (IN. F.S.)	AVG DENSITY ALTITUDE (FT)	AVG OAT (°C)	AVG ROTOR SPEED (RPM)
33000	330	3000	10	225

VERTICAL STATION 440
 BUTT LINE 18
 3/REV

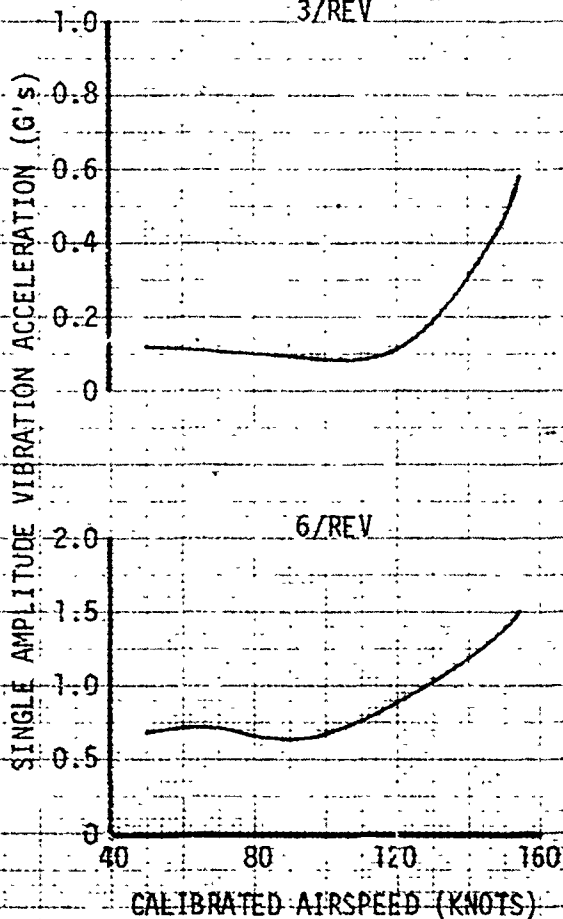


FIGURE 25
VIBRATION CHARACTERISTICS
CH-47C USA S/N 74-22287 FIBERGLASS ROTOR BLADES

AVG GROSS WEIGHT (LB)	AVG CG LOCATION (IN. F.S.L.)	AVG DENSITY (T)	AVG OAT (°C)	AVG ROTOR SPEED (RPM)
33000	330	3000	10	225

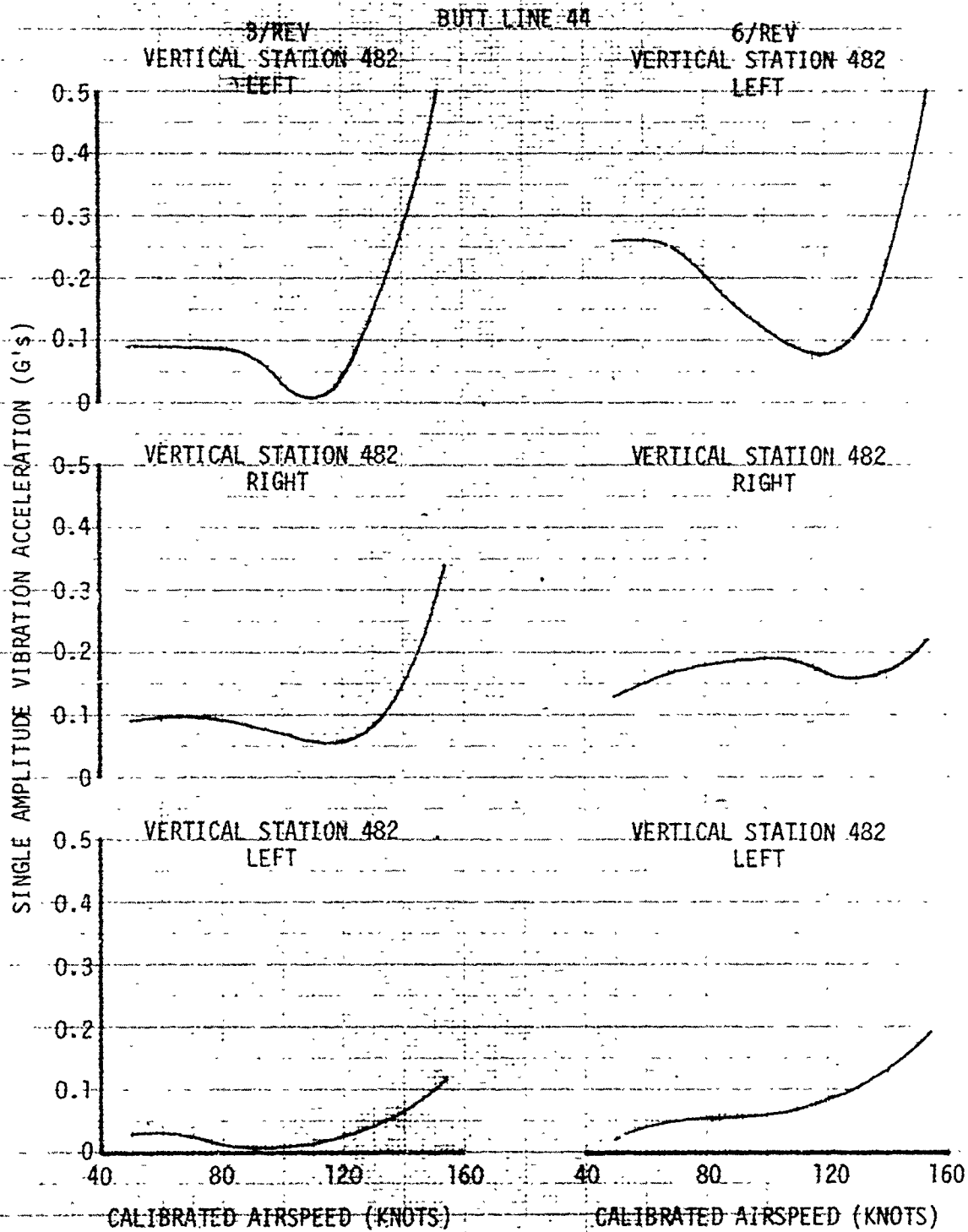
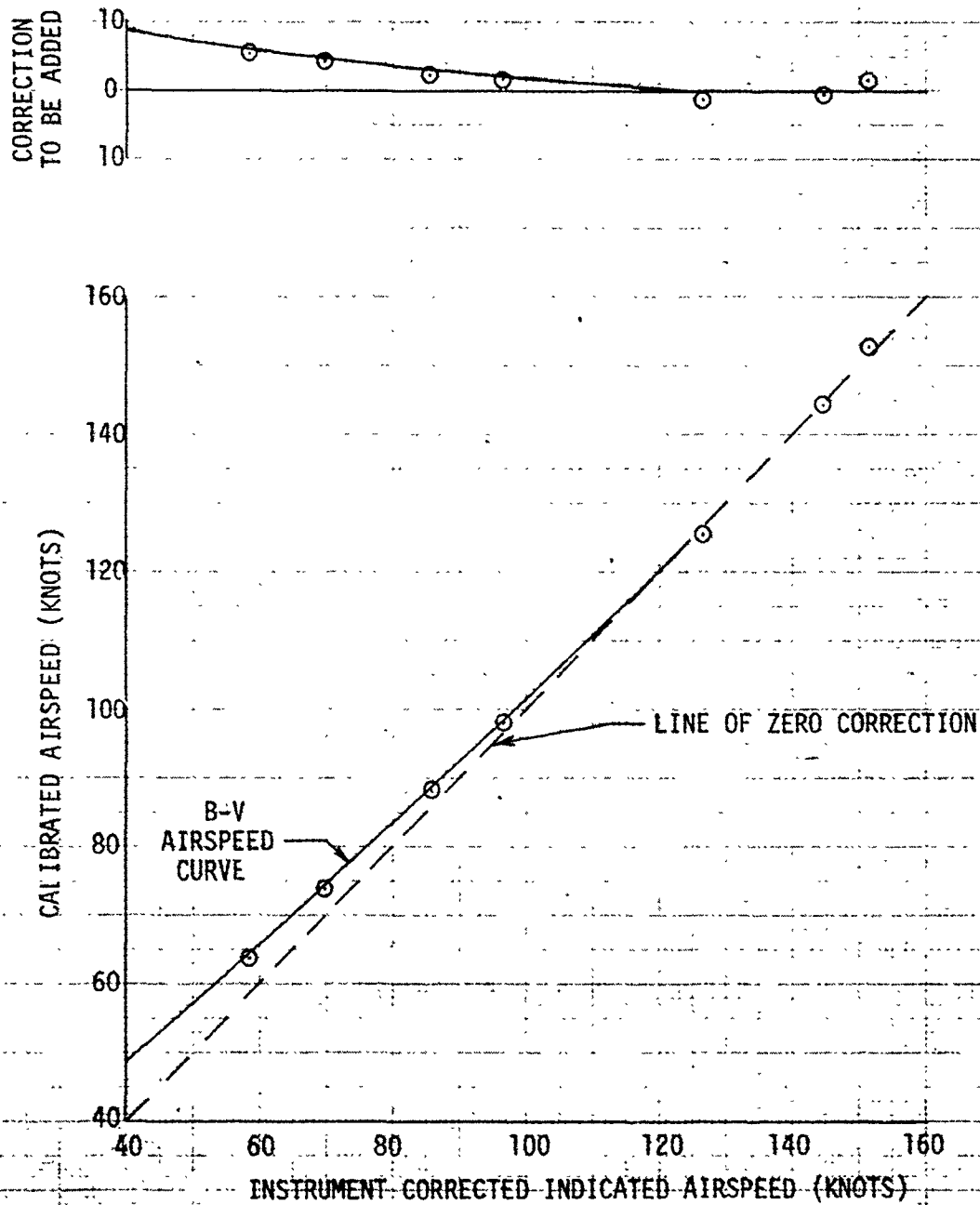


FIGURE 26
 AIRSPEED CALIBRATION
 CH-47C USA S/N 22287 FIBERGLASS ROTOR BLADES
 STANDARD SHIPS SYSTEM
 LEVEL FLIGHT

NOTE: POINTS REPRESENT AEFA DATA USING
 A GROUND SPEED COURSE



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